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The Ubiquitous Hydrogen Bond ❖ The Origins of
Science ❖ Why is an Ant's Trail Straight?
❖ The Ancient Mariners ❖ The Punctured Plane



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Editorial

N Mukunda, Chief Editor

A couple of months ago, in our February 1996 issue, we introduced a new department titled 'Reflections', and presented a contemporary translation of a classic 1931 essay in Bengali by S N Bose on 'The Crisis of Science'. Our intention in this department is to provide interesting material on the history and philosophy of science, and offer a broader perspective than can be realised in specialised articles. In this issue we present the first of a two-part series on 'The Origin of Science' by Gangan Prathap.

Many years ago the physicist Erwin Schrödinger, in his beautiful book titled 'Nature and the Greeks' arising out of his 1948 Shearman Lectures, quoted these words from John Burnet: '...it is an adequate description of science to say that it is "thinking about the world in the Greek way". That is why science has never existed except among peoples who came under the influence of Greece'.

Whether we like it or not, most teaching of modern science emphasizes this point of view, with Europe as the sole inheritor of Greek philosophical thought. On the other hand, we learn from historians of science that the Greek flowering was part of the Egyptian - Phoenician tradition; and that for centuries there had been continuous contact among the peoples of India, China, Central and West Asia, and Greece.

Fortunately there are revivals today of attempts to provide accounts of early Indian efforts and achievements in science and mathematics. It is to be hoped that our own students will have easy access to such studies, written in a balanced way and without exaggeration.

We are pleased to welcome the incomparable R K Laxman to *Resonance* from this issue onwards — our readers are sure to look forward with anticipation to his wry comments on the world of science.



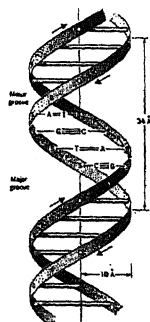
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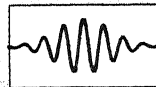
In Africa, a blackthroated honeyguide leads a honeybadger to a wild beehive. In one of the most striking examples of the evolution of mutualistic relationships in the living world. (Illustration by Sanjeev Nayak)



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Charles Robert Darwin (1809- 1882)
(Illustration by Prema Iyer)

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Science Smiles

R K Laxman



How on earth are we to track if the villagers are going to use it for cooking!

Origin(?) of the Universe

4. The First Three Minutes

Jayant V Narlikar

In this part of the series we discuss the standard cosmological model valid close to the big bang epoch. The origin of light nuclei is believed to have taken place within the first three minutes or so when the universe was very hot and dominated by radiation. Subsequently, it cooled down and today we should see radiation decoupled from matter but spread almost homogeneously all over the universe with a black body spectrum. This expectation has been realized by the discovery of the microwave background in 1965.

Probing the Past of the Universe

In the previous part of the series we described the simplest models of the expanding universe, first worked out by Alexander Friedmann. These models contain matter in the form of dust, i.e., pressureless fluid. In this idealized situation we may regard each dust point as a galaxy and the large scale motion of the galaxy population conforms to the Weyl Postulate (see Part 2 of the series). This motion is the one that follows the Hubble law.

In reality, of course, galaxies do have random motions in addition to that of the expansion. The random motions arise because they are members of a cluster wherein the gravitational field of all other members affects the motion of each member galaxy. Normally these motions are in the range of 200 - 300 km/s. Thus if we use the Hubble law, the Hubble motion of expansion of a typical cluster member at a distance of say, 100 Mpc¹ will be around 5,000-10,000 km/s, far larger than the random motions in that cluster. By the same token, for a nearby cluster the random motions may *dominate* the Hubble motion. Our nearest neighbour, the giant galaxy Andromeda is in fact moving



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This six-part series will cover: 1. Historical Background. 2. The Expanding Universe. 3. The Big Bang. 4. The First Three Minutes. 5. Observational Cosmology and 6. Present Challenges in Cosmology.

¹ Mpc = Megaparsec; one parsec equals 3.26 light years $\approx 10^{18}$ cm.

towards us, because of the attraction between it and our galaxy.

² This momentum is to be measured by an observer at the particle with no random motion, i.e., one obeying the Hubble expansion.

³ At redshift z the size of the universe was $1 + z$ times smaller than now.

In the expanding universe one can show that the random part of the momentum of a free particle decreases in inverse proportion to the scale factor.

In the expanding universe one can show that the random part of the momentum² of a free particle decreases in inverse proportion to the scale factor. Thus, at redshift unity³, the random motions would have been typically double those in a nearby cluster. So, as the universe continues to expand, random motions become less and less significant and the approximation to the Weyl postulate becomes more and more accurate.

However, if we are interested in discussing the past history of the universe, the dust approximation may not hold all the way. Our rule of the momentum growth in the past tells us, for example, that a random motion of 300 km/s today would have been close to the speed of light at an epoch of redshift around a thousand. Clearly we must take into account the growth of pressure in the cosmic fluid as we go further back into the past.

The Radiation Dominated Universe

Since we are interested in discussing the behaviour of the universe very close to the big bang, we will skip the more recent epochs and go to one where the random motions were so high that the typical constituents of the universe were moving relativistically, i.e., with near-light speed. At those epochs the galaxies did not (indeed could not) retain their large and bound structures of today. Indeed, we expect that all constituent particles moved freely across space. We thus have a cosmic brew with particles like neutrons, protons, electrons, neutrinos, etc. moving relativistically along with the particles of light, the photons, which of course move with the speed of light. All are moving at random, colliding and interacting in marked contrast to the situation described by the Weyl postulate. In such a state the universe is said to be radiation dominated. Let us look at this scenario more quantitatively.



We shall refer to this epoch as that of the *early universe*. We shall assume, to begin with, that the universe consists mainly of photons. The photons are in constant interaction with charged particles like electrons and positrons and these interactions maintain the photon population in thermodynamic equilibrium. That is, the photons are distributed in momentum space as in *ablack body*. The temperature T and the energy density u of such a distribution are related by the Stefan-Boltzmann law:

$$u = aT^4$$

where the constant a is known as the radiation constant. The pressure of this distribution is given by $p = u / 3$.

The next step is to substitute these quantities in the dynamical equations which drive the universe, viz. the Einstein equations. In the previous part of the series we had done the same for the dust distribution. The two independent relations that emerge are:

$$u S^4 = \text{constant},$$

$$[(dS / dt)^2 + kc^2] / S^2 = 8\pi G u / (3c^2).$$

Standard thermodynamics tells us that the first relation is simply the rule of attenuation of radiation energy density with the

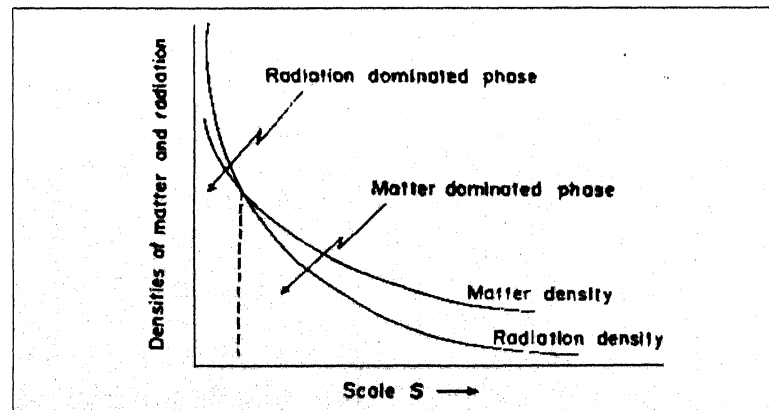


Figure 1 This graph shows how radiation density and matter density fall off as the universe expands, i.e., as the scale factor increases. In the early universe, radiation dominated whereas the present universe is matter dominated. The matter and radiation were of comparable strength when the scale of the universe was approximately a thousandth of its present value.

Today the universe is matter dominated while in the early era it was radiation dominated. As the importance of radiation vis-à-vis matter declines with expansion, the two may have been comparable at an intermediate epoch.

adiabatic expansion of gas. If we compare the expressions of how matter and radiation density fall off in the expanding universe we find that the former falls off as S^{-3} and the latter as S^{-4} . Today the universe is matter dominated while in the early era it was radiation dominated. As the importance of radiation vis-à-vis matter declines with expansion, the two may have been comparable at an intermediate epoch. As we shall see later, the present radiation density is about 10^{-3} of the matter density. Thus the epoch of equality would be around redshift 1000. We can therefore say that around that epoch, the universe switches over from the solution described in this part to that described in the previous part. The second relation describes the gravitational force of the radiation on the expanding gas. We will assume that the curvature term is not important for the solution that we are interested in. This assumption is non-trivial but we will postpone its discussion to Part 6 of the series.

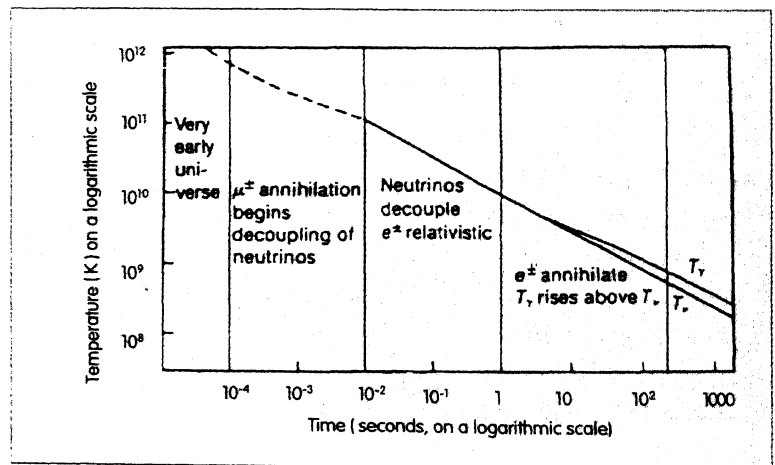
If we ignore the curvature term in the second of the above equations, they can be solved easily. We find, after a little manipulation, that

$$S \propto t^{1/2}$$

and,

$$T^4 = [3 c^2 / (32 \pi G a)] t^{-2}.$$

Figure 2 The time temperature relationship shows how the radiation temperature in the universe falls off with expansion. The smooth curve has discontinuous tangents at epochs when the composition of the universe underwent a phase transition, e.g., when the electrons and positrons annihilated to produce more radiation.



In the latter result we have used the earlier relation between u and T . Note also that t denotes the time elapsed since the epoch when we had $S = 0$, i.e., since the big bang epoch. We thus get from the last relation, the profound result that the temperature of the universe is determinable in terms of its age through constants a , c , G all of which belong to fundamental physics. If we put in the numerical values of these constants then the time-temperature relationship is simply

$$T(\text{Kelvin}) = 1.52. [t(\text{second})^{-1/2}].10^{10}.$$

Thus we conclude that in a universe filled almost purely with radiation, the temperature one second after the big bang was about 15 billion degrees Kelvin.

Primordial Nucleosynthesis

A result of this kind convinced George Gamow in the mid-1940s that the early universe could hold the key to the origin of chemical elements. If the universe started with a relatively simple set of particles like electrons, positrons, neutrinos, muons, pions, neutrons and protons along with photons, then during the first 200 seconds its temperature was in the range $10^{10} - 10^8$ K, high enough to bring about synthesis of neutrons and protons to form chemical nuclei in ascending order of their mass numbers.

The rationale for this conjecture is based on the following. At a temperature T the typical thermal energy per particle is kT , where k is the Boltzmann constant. A typical particle of mass m has rest-mass energy mc^2 . If kT exceeds this value we say that the particle is moving relativistically. By this token, the neutrons and protons ceased to be relativistic when the temperature of the universe dropped below 10^{13} K, whereas for electron-positron pairs the temperature was around 5.10^9 K. Statistical physics formulae tell us that as a species ceases to be relativistic, its number density drops very rapidly with decreasing temperature and it begins to be

The temperature one second after the big bang was about 15 billion degrees Kelvin.



It is possible to argue that although initially the constituent particles were moving relativistically, as the universe continued to expand, its radiation temperature dropped and therefore the motions of these particles slowed down to values small enough for nuclear forces to be able to trap them to form composite nuclei.

less and less important in contributing to the expansion of the universe.

The simple calculation of estimating the temperature that was carried out in the previous section was based on the assumption that of all particles only photons were contributing to the expansion of the universe. A more realistic calculation would take into account the other particles that were relativistic and the extent to which they contributed to the right hand side of Einstein's equations. This calculation modifies the coefficient in the temperature-time relationship from 1.52 to 1.04. Thus our simple derivation captures the physical situation reasonably well and we may use it for approximate estimates of the temperature of the universe.

At the temperatures $10^{10} - 10^8$ K, particle energy is in the range comparable to the binding energy of nuclei like deuterium and helium. Thus, it is possible to argue that although initially the constituent particles were moving relativistically, as the universe continued to expand, its radiation temperature dropped and therefore the motions of these particles slowed down to values small enough for nuclear forces to be able to trap them to form composite nuclei. Since the universe provided a rapidly changing environment, it was necessary to include this in the calculations along with the details of nuclear reaction rates in order to determine the actual abundances of various nuclei.

Gamow and his younger co-workers Ralph Alpher and Robert Herman carried out calculations of this kind in the late 1940s. These calculations were redone by others as improved nuclear reaction data became available. The most comprehensive such attempt was in 1967 by Robert Wagoner, William Fowler and Fred Hoyle. Today high speed computers are needed to refine these results, but the essential conclusions have not changed since 1967. What are these conclusions?

The entire process of primordial nucleosynthesis is completed in

a very limited period, say in about the first three minutes. After this the universe has cooled down so much that the nuclear furnace is switched off. However, contrary to what Gamow had expected, the process of primordial nucleosynthesis is not able to deliver nuclei with mass numbers of 5 or more. The process thus produces mainly He^4 and very tiny quantities of deuterium, tritium, He^3 and also extremely small quantities of nuclei like Li^6 , Li^7 and B^{11} . For the commonly found elements like carbon, oxygen, etc including metals like iron, one must turn to another scenario altogether. In 1957, in a pioneering paper in *Reviews of Modern Physics*, Geoffrey and Margaret Burbidge along with Fowler and Hoyle showed how stars in various stages of their evolution produced all these elements. As it happens, stars are not so effective in producing the light nuclei that the early universe is able to generate. Thus there seems to be some complementarity in the two scenarios.

The entire process of primordial nucleosynthesis is completed in a very limited period, say in about the first three minutes. After this the universe has cooled down so much that the nuclear furnace is switched off.

Relics of the Early Universe

Physicists by now will be inclined to argue that all this is fine so far as speculations go; but can these ideas on the early universe be verified through experiments or observations? In short, they will be looking for relics of the high energy activity that went on during the first three minutes, in the history of the universe much as archaeologists look for relics of a bygone era. Fortunately the early universe model does provide two important relics. We will describe them here although we will discuss them in the light of observations in Part 5.

One relic is the light nuclei that we just discussed. For example, the primordial abundance of helium is expected to be in the range 23-24 per cent by mass while that of deuterium may be in the range $10^{-6} - 10^{-5}$. Stellar nucleosynthesis provides additional helium to the extent of only about ten percent of the primordial value whereas no stellar process is as yet known for producing deuterium. These and other light nuclear abundances are thus the relics of the early era.

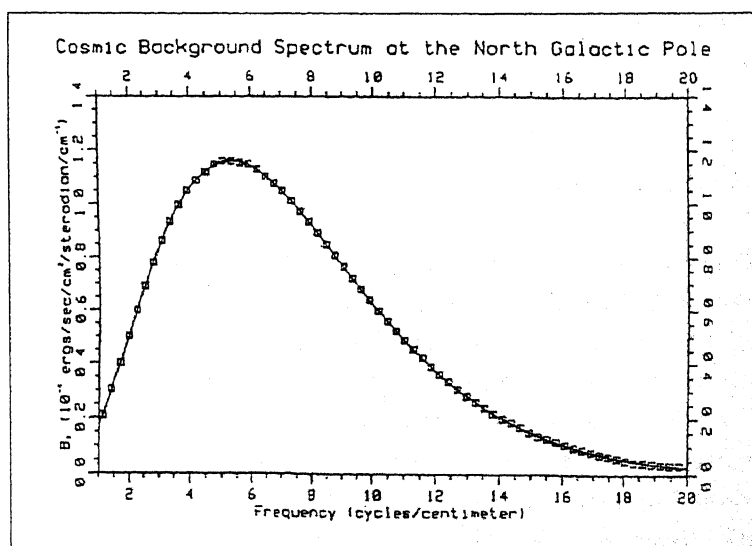


The second important relic, first predicted by Alpher and Herman in 1948 in a paper in *Nature*, concerns radiation. Recall that we started with radiation as the main component of the primordial universe. What has happened to it today? In our discussion we had assumed that the radiation was in thermodynamic equilibrium in the early universe because it was in continuous interaction with charged particles through electromagnetic interactions. Charged particles are largely electrons which continue to remain free a long time after the light nuclei are formed. Thomson scattering by the electrons is sufficiently powerful to block the radiation from travelling coherently over cosmological distances. The early universe was, in technical jargon, optically thick and the radiation had the spectrum of a black body.

However, as its temperature dropped below the 3000-4000 K mark, the randomly moving electrons became too slow to escape being trapped by protons via the Coulomb force of electrical attraction. Thus the electrons get into orbitals around protons and form neutral atoms of hydrogen. The trapping stage is governed by the *Saha ionization equation* discovered by Meghnad Saha in the 1920s in the particular case of stellar atmospheres. So at the temperature mentioned above, the radiation finds itself free from the charged scatterers!⁴ This is the epoch of last scattering of

⁴ As temperature is raised, a physical system can be found with increasing probability in states of higher energy. Since it takes energy to remove electrons from an atom, this process (called *ionisation*) becomes more and more important at high temperatures. Saha's noteworthy contribution in deriving his formula was to correctly account for the *number of states* available to the electron once it is freed. This depends on the temperature but also the volume of space available in between the atoms. This effect is very important. Neglecting it would give a completely wrong answer (100,000 K) for the temperature of recombination mentioned in the text!

Figure 3 The spectrum of the microwave background as measured by the COBE satellite. The smooth curve is the blackbody curve that best fits the data.



the cosmic radiation which thereafter remains decoupled from matter. Since the electrons combine with protons at this epoch it is sometimes (erroneously) called the recombination epoch.

The physics of such radiation tells us that it would adiabatically cool down as the universe expands, while retaining its primordial stamp of a black body radiation. The temperature itself would drop as S^{-1} . Its magnitude at the present epoch, however, cannot be determined by the early universe models but has to be taken as a given observational input.

The discovery in 1965 by Arno Penzias and Robert Wilson of the uniform and isotropic microwave background at a wavelength of about 7 cm was thus regarded as a vindication of the above early universe scenario. Subsequent studies at many other wavelengths culminating in comprehensive measurements by the Cosmic Background Explorer satellite in 1989 established the blackbody nature of its spectrum with a temperature of 2.735 ± 0.06 degrees Kelvin. In total energy content this microwave radiation background far exceeds any other radiation arising from other causes of astrophysical origin at various wavelengths.

If the present value of the radiation temperature is denoted by T_0 , the temperature of the radiation at epoch of redshift z would be given by $T_0(1+z)$. Hence the last scattering epoch had redshift around 1000-1500.

Thus if we use this value of temperature for the radiation energy density we find that its magnitude is about $4 \cdot 10^{-13}$ erg / cm³ compared to the present energy density of visible matter estimated around $3 \cdot 4 \cdot 10^{-10}$ erg/cm³ (a more complete discussion will be given in Part 5). That is, *matter dominates over radiation by some three orders of magnitude*. This result was used earlier by us to decide the epoch when the universe switched over from being radiation dominated to matter dominated. Note that this epoch is roughly the same as the epoch of last scattering.

The discovery in 1965 by Arno Penzias and Robert Wilson of the uniform and isotropic microwave background at a wavelength of about 7 cm was regarded as a vindication of the early universe scenario.



Concluding Remarks

This part essentially summarizes the theoretical basis of big bang cosmology. To proceed further it is necessary to take stock of the observational constraints to see whether our picture developed here meets the basic observational checks. This we will do in Part 5 of this series.

The work on the early universe has prompted further speculations about what the universe was like even closer to the big bang epoch. As we shall see in Part 6 these speculations take us close to fundamental particle physics where physicists are interested in speculating about the ultimate structure of matter and its origin.

Suggested Reading

S Weinberg. The First Three Minutes ... Basic Books. 1977.

J V Narlikar. Introduction to Cosmology... Cambridge University Press, Foundation Books. 1993.

John Barrow. The Origin of the Universe. Weidenfeld and Nicolson, London. 1994.

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Life: Complexity and Diversity

3. Growing Larger

Madhav Gadgil

Living organisms continually evolve to occupy newer environmental regimes. In the process they develop more complex structures and grow to larger sizes. They also evolve more intricate ways of relating to each other. The larger, more complex organisms do not replace the simpler, smaller ones, rather they come to coexist with them in increasingly complex ecosystems. This promotes a continual increase in the diversity of life over evolutionary time.

Ways of Life

Decomposing, photosynthesizing and feeding on other organisms are three broad ways of organizing fluxes of energy necessary for the maintenance and propagation of all life (*Figure 1*). But



Madhav Gadgil is with the Centre for Ecological Sciences, Indian Institute of Science and Jawaharal Nehru Centre for Advanced Scientific Research, Bangalore. His fascination for the diversity of life has prompted him to study a whole range of life forms from paper wasps to anchovies, mynas to elephants, goldenrods to bamboos.

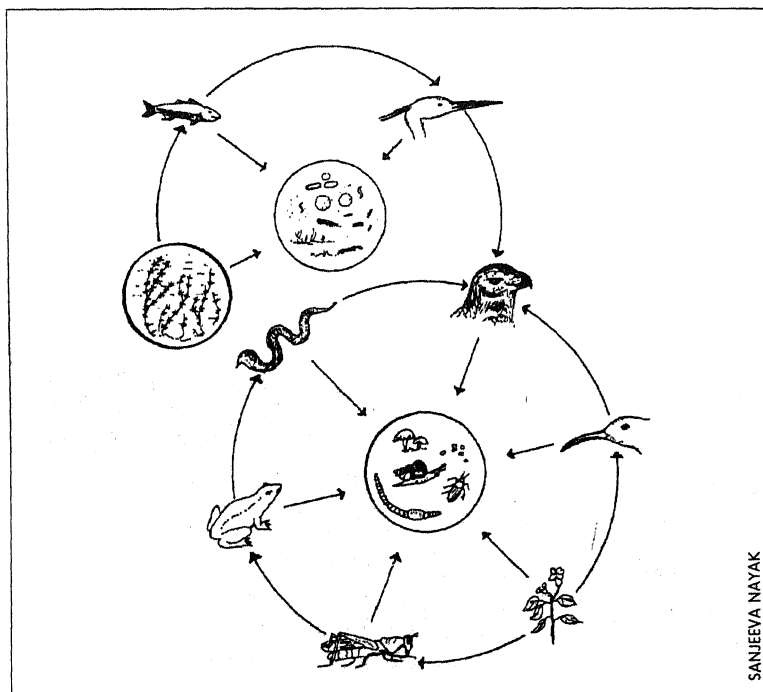


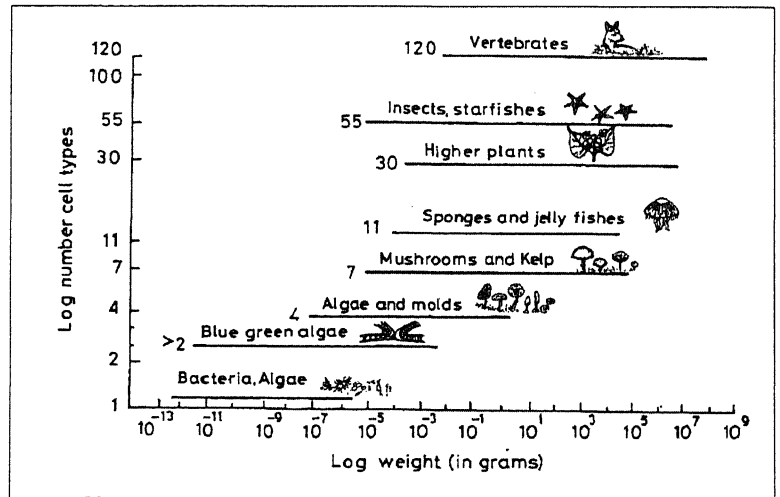
Figure 1 Decomposition, or living off preformed organic molecules is the oldest way of life and is still at the centre of both terrestrial and aquatic food webs. Autotrophy, or manufacture of organic molecules through photosynthesis came next; followed later by heterotrophy or feeding on other living organisms giving rise to the elaborate food webs of present day ecosystems.

As living organisms have adopted these newer ways of life and invaded an ever greater range of habitats, they have assumed larger sizes and more complex structures.

living organisms have created an infinity of variations around these themes. Among the green plants, for instance, are some that do well in bright, open light, while others thrive in the dim light of the forest floor. There are plants that grow well in swampy places and others that prefer the desert sand. Animals graze on grass or browse on leaves, burrow inside stems or gnaw on roots. There are predators that sit and wait for the prey to be caught in their traps or webs, and predators that pursue and run their prey down. There are parasites that live inside cells of other organisms, even becoming a part and parcel of their nucleic acids, and others that live in their gut or on their skin. Honeybees and other insects are rewarded by flowering plants with nectar and superabundant pollen for the services of pollination rendered by them.

As living organisms have adopted these newer ways of life and invaded an ever greater range of habitats, they have assumed larger sizes and more complex structures (Figure 2). Bacteria subsisting as decomposers on dead organic matter are among the simplest, smallest organisms. It has been but a small step for them to live inside bodies of other living organisms, and feed on living organic matter, without any great elaboration of structure. But when creatures took to tapping light energy, they had to produce special pigments, like chlorophyll. They also had to elaborate protective structures as well as special chemicals or enzymes to

Figure 2 *The simplest and smallest organisms are composed of single cells; the more complex, larger organisms like us are made up of billions of cells. But just as the whole complex machinery of life is constructed from a small variety of building blocks, the most complex organisms are made up of a small number of basic cell types. This graph based on the work of J T Bonner, plots the number of cell types against size of the organisms on a logarithmic scale.*



SANJEEVA NAYAK

make sure that the oxygen released did no damage. The efficiency of the process of photosynthesis was further enhanced by concentrating the chlorophyll in specially structured bodies. This was accomplished by the establishment of cellular co-operatives, with the elaboration of much larger cells of higher organisms which contained within them descendants of smaller cells that now served as oxygen processing mitochondria and light trapping chloroplasts. Cells of plants and animals with their mitochondria and plastids are much larger than those of bacteria. But there are distinct limitations to how large a single cell can become, the largest being an egg of the ostrich, largely loaded with stored food. So, to achieve larger sizes favoured for instance by the advantage that larger organisms have in getting at resources like light or in escaping predation, plants and animals have developed yet another form of cellular co-operation. They have become multicellular. Indeed, today the vast majority of living organisms are multicellular. As plants invaded land, a whole range of new structures had to be formed to resist rapid loss of water and to fight gravity. So plants began to produce large quantities of tough yet flexible molecules of cellulose. Cellulose is today one of the most

To achieve larger sizes plants and animals have developed yet another form of cellular co-operation. They have become multicellular.

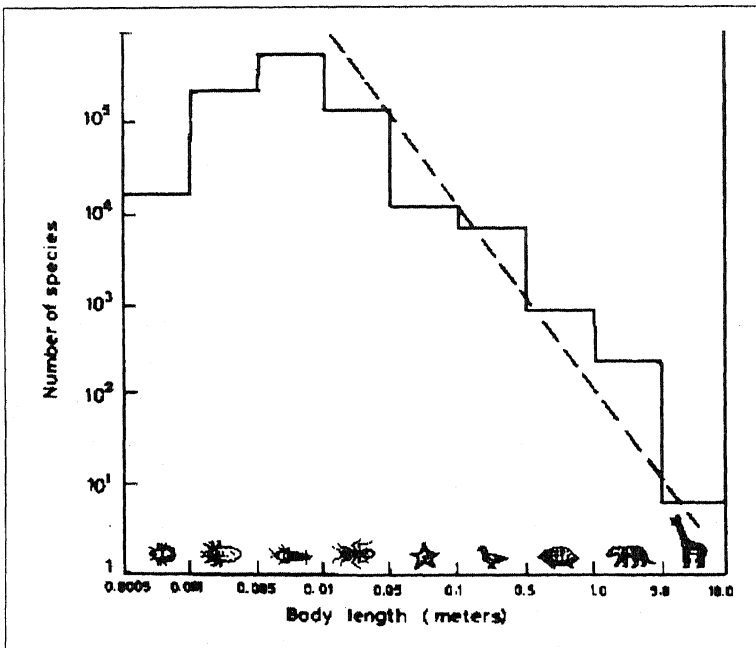


Figure 3 The possibilities of diversity of designs obviously increase with the size and complexity of an organism. It is therefore to be expected that there is a smaller variety of species of the smallest, simplest organisms such as bacteria. But the variety of species increases with size only up to a size of 5 mm to 1 cm. Beyond this, presumably physiological limitations come into play so that the diversity of species declines with increasing size (this figure is based on the work of Robert May).

SANJEEVA NAYAK

Feeding on other plants and animals locks many animals into a contest with their victims. While the victims continually evolve new ways to foil the predators, the predators evolve to overcome these defences.

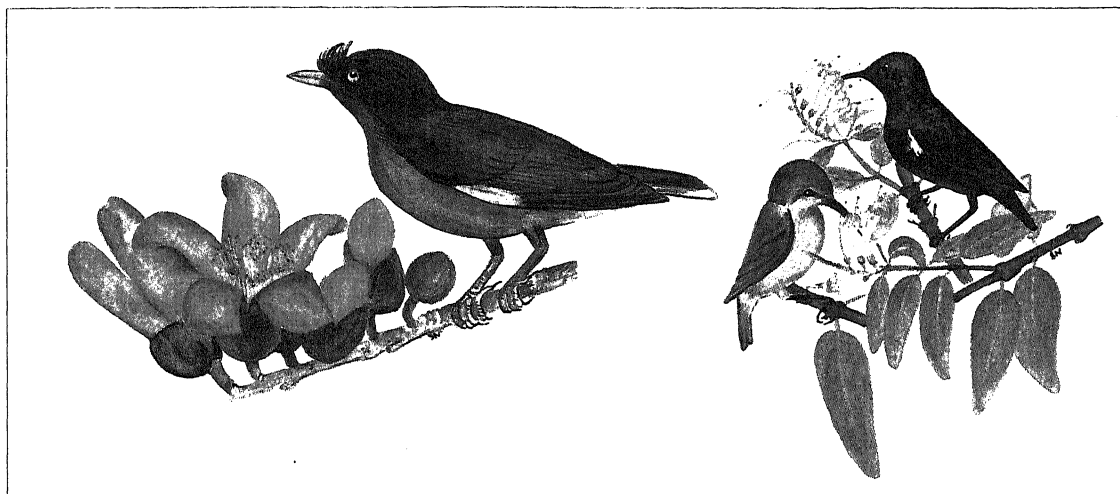
abundant of molecules on earth. Once established on land began to compete with each other for light and water. In the humid environments, light becomes the key resource plants get locked into a race to outgrow each other. So produce more structural matter and grow taller until they reach the gigantic proportions of a redwood or a baobab tree (*Figure 3*).

Feeding on other plants and animals locks many animals into a contest with their victims. While the victims continually evolve new ways to foil the predators, the predators evolve to overcome these defences. Thus while antelopes become ever fleetier or cheetahs evolve to run faster and faster. While rhinos and elephants evolve to a large size and thick hides, lions and tigers evolve to be big enough to tackle their young prey, if not the full adults. In the rain forest the lush green leafy matter is consumed by myriads of insects. Rain forest plants produce a whole range of toxic chemicals to counter this threat. In turn, the insects evolve means of neutralizing these poisons. It is this chemical warfare that is responsible for the evolution of many valuable drugs that humans extract from plants of the humid tropics.

Mutual Aid

Some of the most attractive manifestations of life such as colourful flowers and delectable fruits have evolved in contexts of mutual help.

But animals, plants and microbial species not only subsist on each other, they also help each other. Indeed, some of the most attractive manifestations of life such as colourful flowers and delectable fruits have evolved in contexts of mutual help. The early plants relied on wind and water to carry pollen and disperse seeds. But the operation of these physical factors is a chancy affair. So plants evolved flowers to attract pollinators and reward them with sugary nectar. Pollen would be wasted if deposited on a flower of a different species. So plants have developed flowers of different sizes, shapes and colour patterns to ensure that a pollinator visits only one flower to another flower of the same species. They have also specialised in being served by a particular type of pollinator. So the bright flowers of the silk cotton tree attract juncos with their



SANJEEVA NAYAK

brush of modified feathers over their beaks, and sunbirds insert their slender, curved beaks inside the tubular flowers of mistletoes (Figures 4, 5). Honeybees visit the blossoms of jamun, and night flying moths those of the night queen.

Plants have also developed fruits whose flesh rewards animals for dispersing their seeds. Again there are myriads of specializations directed at many different animals. Mangoes hang on long stalks to help bats pluck them, while sandal berries attract bulbuls. There are other intricate mutualisms as well. Very few living organisms can produce chemicals capable of breaking down the tough molecules of cellulose. Certain microorganisms can do this and animals like cattle and deer have special chambers in their gut to lodge these helpers. Wax is yet another kind of molecule that few organisms can break down or extract useful energy and material from. Plants produce wax to prevent water loss from their leaves and to resist animal grazing. Animals like honeybees secrete wax to construct their hives. Such a honeybee hive with its stored food in the form of honey, eggs, larvae and pupae is a rich and attractive source of food for many animals. But it is a food source most ably defended by worker bees that launch suicidal attacks on potential predators braving certain death as they firmly embed their stings in the bodies of their enemies. Animals in turn have developed elaborate structures and behaviour patterns to

Figure 4 (top left) *The pollen of the red silk cotton tree attaches itself to the pollen brush at the base of the jungle myna's beak.*

Figure 5 (top right) *The slender curved beak of the purple sunbird enables it to get at the nectar in the long tubular flowers of mistletoes..*

Pollen would be wasted if deposited on a flower of a different species. So plants have developed flowers of distinctive sizes, shapes and colour patterns to ensure that a pollinator moves to another flower of the same species.



overcome these defences. One such predator is the honeybadger equipped with a thick coat of fur and a very loose skin which keep the bee stings out of reach of most of its organs. But honeybee hives are at a height and honeybees operating in the forest canopy are not easily visible to the badger. They are however much more easily tracked by a bird called the honeyguide. The honeyguide on its own is too frail to attack a honeybee hive. It has therefore evolved a mutualistic relationship with the honeybadger (*see cover picture*). When a honeyguide locates a hive it looks for its ally, the honeybadger and freezes in a characteristic posture. The honeybadger then begins to follow it on the ground. The honeyguide flies in stages towards the hive with the badger following it all the way. The honeybadger then successfully attacks the hive and feasts on the honey, the eggs, the larvae and the pupae. But it cannot digest the wax which is left behind. The honeyguide feeds on the wax, for it has yet another ally, a protozoan lodged in its gut that helps it digest the wax. Thus have organisms continually evolved more and more complex structures and behaviour patterns as they have devised ever more diverse ways of getting at energy and material resources to keep them going.

Growing Diversity

In this manner life has expanded during its three and a half billion year history on the earth, evolving larger and more complex organisms. The bigger and the more complex have added on to, and not replaced, the smaller and the simpler. So, when a branch of a giant banyan tree snaps in a storm and begins to rot, this, one of the largest and most complex of all creatures nourishes decomposing bacteria which are among the simplest and smallest of creatures. The history of life has therefore been a process of continual increase in the variety of life. It is a process that feeds on itself. The banyan tree is one of a group of strangler figs — trees that are adapted to begin their life on top of other trees. Only after other trees have formed a forest canopy could such stranglers have evolved. Growing in litter accumulated in crevices and hollows on

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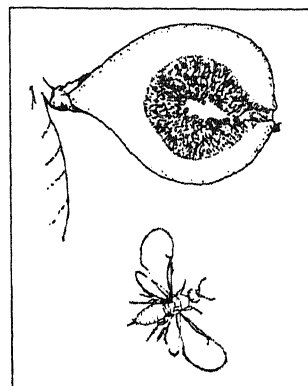


host trees, the strangler figs are freed from the compulsion to produce seeds for germination in a restricted season, such as at the beginning of the monsoon. So unlike most other tree species, figs have taken to fruiting at all times of the year. This requires pollinators the year round. Since there would be few other trees to pollinate in the general off season, figs need specialized pollinators. A special group of insects, the fig wasps, have evolved to fill in this role (*Figure 6*). There is a whole diversity of such fig wasps, often a separate species specialized to a given species of figs.

The availability of fig fruits throughout the year greatly improves the availability of fleshy fruits in their tropical forest habitat. This is especially significant in months when almost no other fleshy fruit is being produced. Figs help monkeys and fruit eating birds like barbets and fruit pigeons tide over such a pinch period. This has made possible the evolution of many animals specialized on a fruit diet. In turn the fruit eating animals support many species of parasites, which have evolved to live on or inside the bodies of individuals of one particular host species. Some of these parasites, such as hair lice, have their own specialist parasites: bacteria, viruses and fungi.

Packing Species

The diversity of living organisms has exploded, hand in hand with the evolving complexity of their interactions in communities. In the dance drama of life the plot becomes ever more intricate, calling for newer roles and recruiting more players. And there are many such dances in all corners of the earth, sharing some actors, but not many others. That adds another dimension to the diversity of life. Thus red-whiskered bulbuls replace red-vented bulbuls as one goes from drier to moister woodlands. And different species of snails walk up a beach in the zone where tides wash back and forth. Along all gradients where the environment changes, for instance, from moister to drier conditions, as one goes away from a river bed, or as one goes from a region of higher to one of lower rainfall, the set of species changes. This also



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Figure 6 *The entire development of a fig wasp takes place inside a fig fruit, with the fertilized female emerging to seek fresh figs in which to lay eggs.*

The diversity of living organisms has exploded, hand in hand with the evolving complexity of their interactions in communities. In the dance drama of life the plot becomes ever more intricate, calling for newer roles and recruiting more players.

There is yet another reason for the variety of living organisms on the earth, and that is *geographical turnover*.

happens as one goes from a warmer to a cooler region, for instance up the Himalayan slopes, or northwards from Kanyakumari to Kashmir. These changes occur because a given species is best adapted to a specific environmental regime, and is replaced by a better adapted species as the regime changes. Ecologists term this component of diversity *species turnover*. The term *species packing* is used for the diversity of a large number of species occurring together in the same community.

There is yet another reason for the variety of living organisms on the earth, and that is *geographical turnover*. India has two species of wild goats or tahrs that haunt the rocky crags of high hills. The southern Western Ghats harbour the Nilgiri tahr, while another species of the same genus, the Himalayan tahr lives in the eastern Himalayas. The Indian continent supports four species of macaque monkeys: the bonnet macaque in the drier forests south of the Godavari river, the liontailed macaque in the wet forests of Western Ghats, the rhesus macaque north of Godavari and the Assamese macaque in the Brahmaputra valley. Islands too tend to have their own sets of species — the birds, Nicobar hornbill and Nicobar megapode, and the coconut crab are restricted to the Andaman-Nicobar islands.

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Suggested Reading

J T Bonner. *The Evolution of Complexity by Means of Natural Selection*, Princeton University Press, Princeton. pp. 260, 1988.
M H Nitecki.(Ed.) *Evolutionary Progress*, The University of Chicago Press, Chicago. pp. 354.1988.



Deceit in History ... Gregor Mendel, the Austrian monk who founded the science of genetics, published papers on his work with peas in which the statistics are too good to be true. (from *Betrayers of the Truth* by W Broad and N Wade)

Fascinating Organic Transformations

2. The Ubiquitous Hydrogen Bond

Subramania Ranganathan

Hydrogen bonds can transform simple molecules into beautiful architectures. This is well illustrated in this article.

Organic transformations are generally assumed to involve reactions in which covalent bonds are made, broken or rearranged. We can think of a wider connotation for the term 'transformation' if we include changes brought about by non-covalent forces. Although such interactions are weaker, the transformations can be quite dramatic, in terms of resulting structures and properties. In this article, let us consider the most important non-covalent interaction, viz., the hydrogen bond and the wide variety of ways in which this bond can lead to almost magical transformations of even simple organic molecules.

Definition of a Hydrogen Bond

A hydrogen atom bonded to an electronegative atom like oxygen or nitrogen has a small positive charge, due to bond polarization. It can therefore have an attractive interaction with any electron rich group in the vicinity. Usually, electronegative atoms have residual lone pairs available for such interaction. Hence, a fragment such as $X-H \cdots Y$, in which both X and Y are electronegative atoms has a stabilizing interaction. This weak force is called the hydrogen bond.

Electrostatic interactions are quite common in molecules with uneven charge distributions. The importance given to hydrogen bonds is due to several reasons. Hydrogen bonds are ubiquitous and easily recognisable. Importantly, the interaction has sufficient directional character for it to be classified as a 'bond'. The X-H unit prefers to be collinear with the electron pair on Y. But some



After nearly a three-decade long innings as an inspiring teacher and researcher at IIT Kanpur, S Ranganathan is now at RRL, Trivandrum. He and his chemist wife, Darshan, plan to set up (without government assistance) "Vidyanantha Education Centre", to promote education, art and culture.

Hydrogen bonds are ubiquitous, easily recognisable and have sufficient directional character.

The directionality of hydrogen bonding is responsible for creating beautiful structural frameworks from simple building blocks.

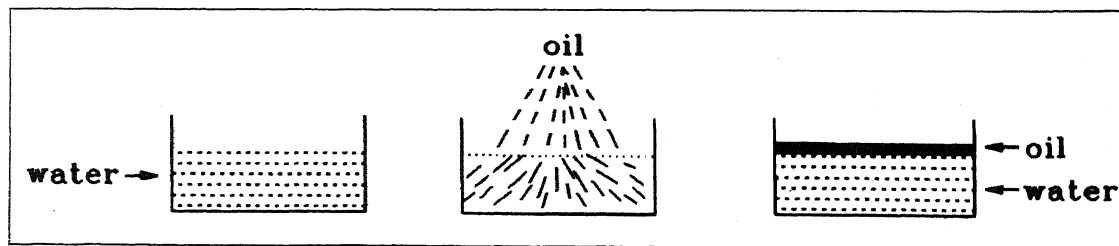
flexibility is allowed, since the interaction is not quite strong (especially compared to covalent bonds). The directionality of hydrogen bonding is responsible for creating beautiful structural frameworks from simple building blocks. It is possible to create chains, sheets, helices, three-dimensional networks, etc., using hydrogen bonds as the principal glue. The resultant shapes are not merely aesthetically pleasing but the transformed molecules become endowed with remarkable properties as a result of hydrogen bonding.

The importance of the hydrogen bond was stated clearly and forcefully as early as in 1939 by Linus Pauling in the first edition of his celebrated book *The Nature of the Chemical Bond*:

“Although the hydrogen bond is not a strong bond (its bond energy, that is, being in most cases in the range 2 to 10 kcal/mol) the energy of the reaction $X-H+Y \rightarrow XH \cdots Y$, it has great significance in determining the properties of substances. Because of its small bond energy and the small activation energy involved in its transformation and rupture, the hydrogen bond is especially suited to play a part in reactions occurring at normal temperatures. It has been recognized that hydrogen bonds restrain protein molecules to their native configurations, and I believe that as the methods of structural chemistry are further applied to physiological problems, it will be found that the significance of the hydrogen bond for physiology is greater than that of any other single structural feature”.

Figure 1 A dispersion of oil in water quickly gets ‘oiled out’.

Seldom in science has any statement been so prophetic. In the intervening five and a half decades, the mural that encompasses the domain of hydrogen bonds has covered a wide area. Even a



reasonable coverage of the theme in these pages would be difficult. Faced with this predicament, only a few representative examples are provided to highlight the art and science in hydrogen bonding networks.

Hydrogen Bonding in Water

As the most abundant liquid on the earth's surface, water is vital for the support of life. Even though the molecular formula of water is H_2O , it does not exhibit properties which you would expect from comparison with H_2S (or with NH_3)! Strong hydrogen bonding in water increases the density, the melting and boiling points, and lowers the acidity as proton transfer interferes with the hydrogen bonded network. Hydrogen bonding in water is also primarily responsible for the well known fact that water and oil do not mix. The 'oiling-out' effect is schematically shown in Figure 1.

We showed how diamondoids can be made using wandering

Strong hydrogen bonding in water increases the density, the melting and boiling points, and lowers the acidity.

It is also primarily responsible for the well known fact that water and oil do not mix.

Figure 2 Assembly of water molecules in diamondoids.

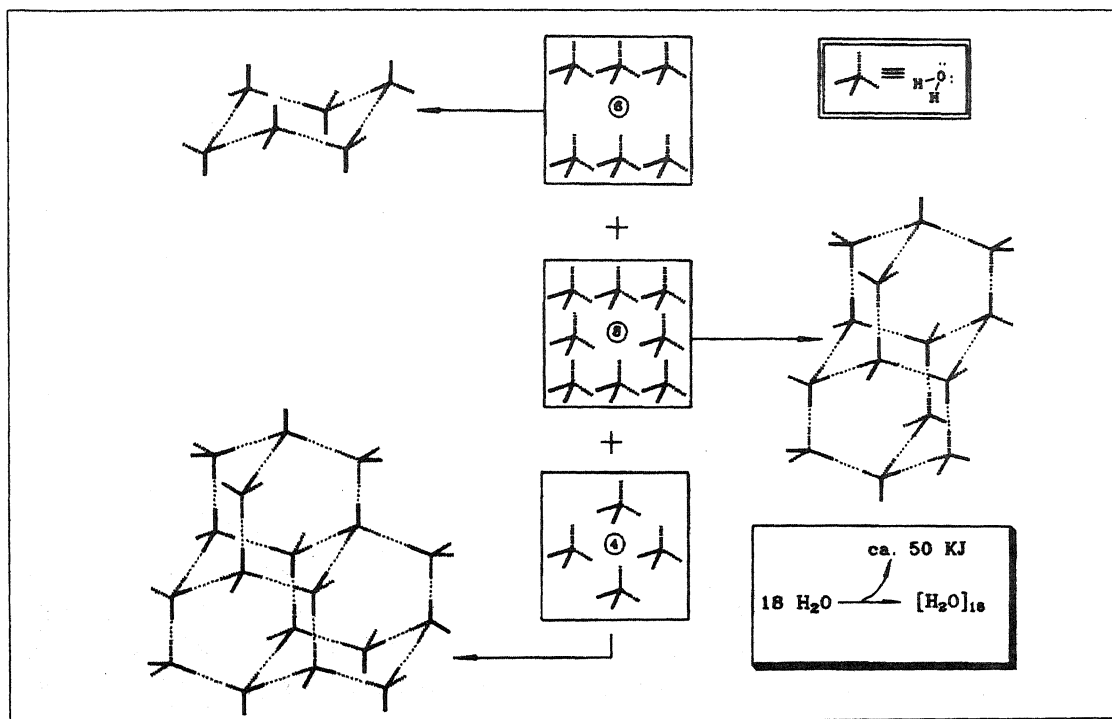
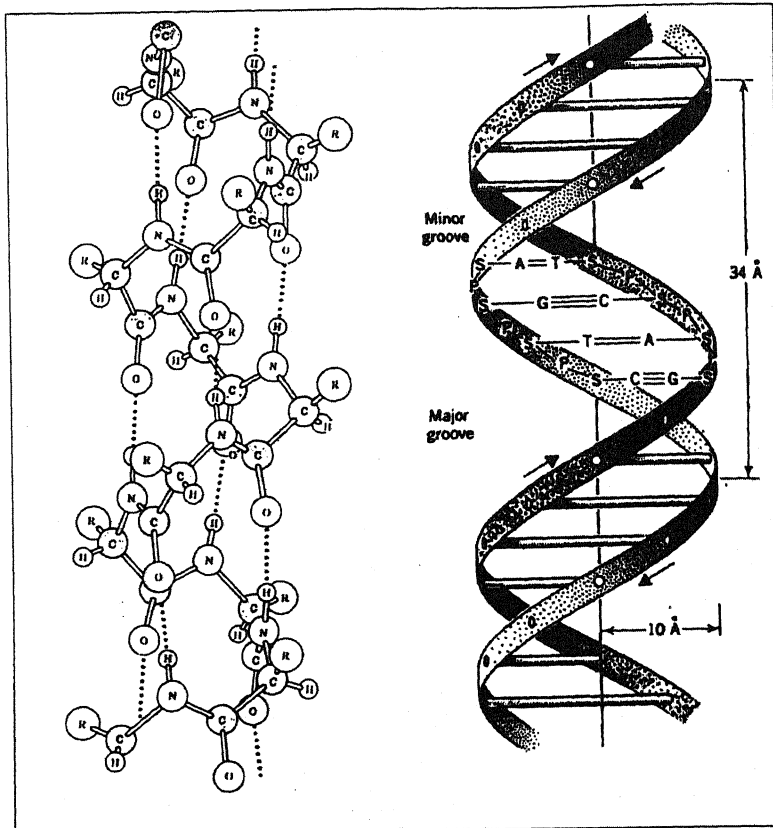


Figure 3 (left) An α -helix. Note the N-H...O hydrogen bonds parallel to the helix axis.

Figure 4 (right) Double helix of DNA: here, P means phosphate diester, S means deoxyribose, the A-T double bond is the adenine-thymine pairing and the G-C triple bond is the guanine-cytosine pairing.



sigma bonds in a previous article (*Resonance*, Vol. 1, No. 1, 1996). It may come as a surprise that water can form similar structures entirely through hydrogen bonds. The water molecule has two donor sites (the O-H bonds), and two acceptor sites (the lone pairs on the O atom). This creates a perfect setup for a self-assembly to diamondoid structures, which is conceptually presented in *Figure 2*. It can be estimated that the transformation of 18 g of H_2O to 18 g of *water* can give rise to ca. 50 kJ stabilization. Such high stabilization to weight ratio cannot be matched through other non-covalent interactions.

The existence of carboxylic acids as dimers, even in the gas phase, is also because of strong hydrogen bonding. Hydrogen bonding can also significantly affect chemical reactivities (one example is found elsewhere in this issue!).

Hydrogen Bonding in Biological Systems

Life in simple terms represents a symbiosis of the functional systems (enzymes, proteins) and the information system (DNA, RNA) driven by regulated external energy inputs. It is interesting to see that one of the main structural motifs of proteins and enzymes, the α -helix, is stabilized by intrachain hydrogen-bonds which are *parallel* to the helix axis (Figure 3), whereas, the double-helical structure of DNA has the base-pairing hydrogen bonds *perpendicular* to the helix axis (Figure 4). It is pertinent to mention here that in proteins there is another distinct sheet like structural element (a β -sheet) which is also produced by hydrogen-bonding between extended chains of polypeptides.

It is interesting to note that one of the main structural motifs of proteins and enzymes, the α -helix, is stabilized by intrachain hydrogen-bonds

Hydrogen Bonding in Biomimetic¹ Systems

The Watson-Crick DNA duplex highlighted the importance of the specificity of hydrogen bonding between the base pairs Adenine (A) and Thymine (T), and Guanine (G) and Cytosine (C), (shown in Figure 5) in determining the properties of DNA. The proposal stimulated interest in creating other sets of molecules which bind specifically to each other, leading to the birth of a new discipline called 'Molecular Recognition'.

¹The word 'biomimetic', coined by Ronald Breslow, essentially means imitating (or mimicking) a biological process (or a key part of it) using simple organic and/or inorganic molecules and complexes.

Of the thousands of examples available in this area, the most imaginative perhaps is the molecular replication model invented

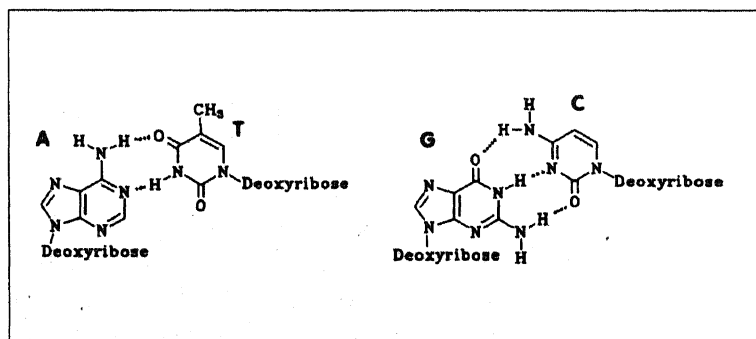
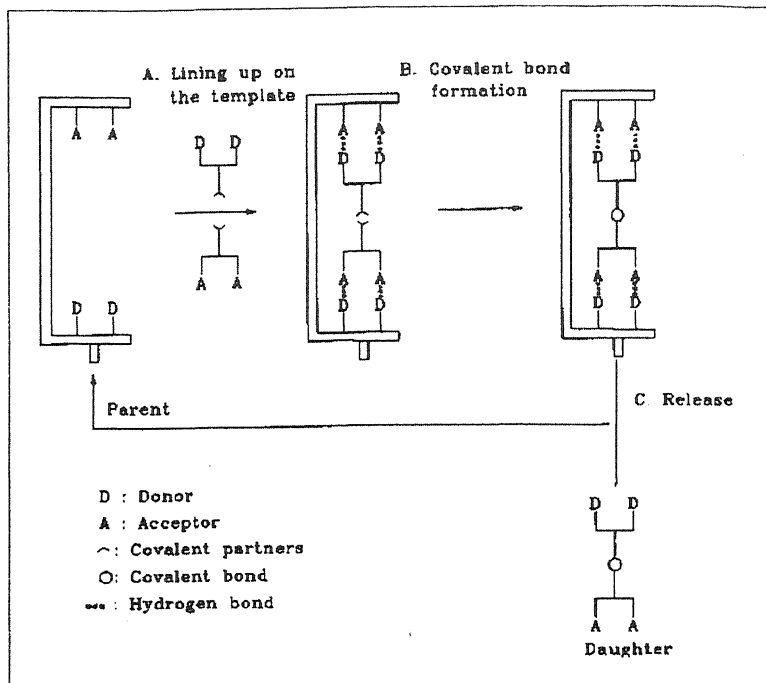


Figure 5 Hydrogen-bond directed mutual recognition of Adenine-Thymine (left) and Guanine-Cytosine (right).

Figure 6 Model showing catalysis of a reaction by a template which holds reacting partners through H-bonds.

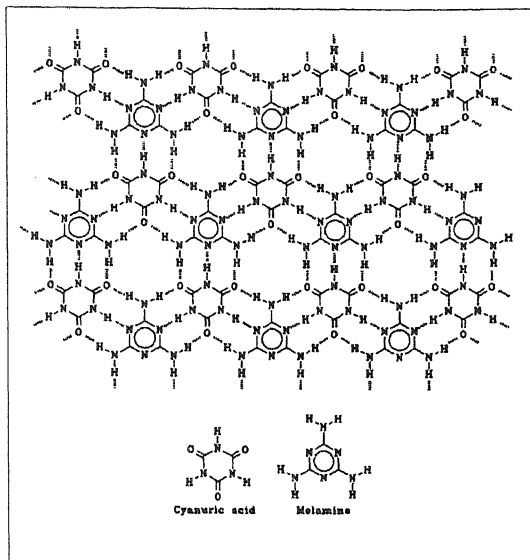
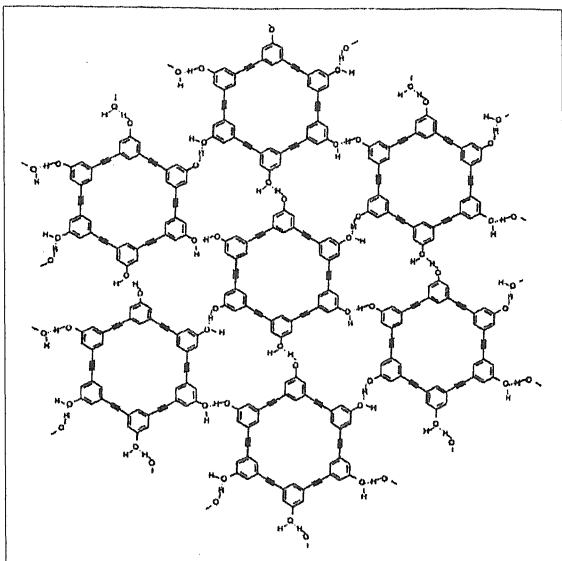


by Rebek. Avoiding the molecular complexity involved, the principle can be best understood by a model for replication shown in *Figure 6*. A template, drawn as a hacksaw, is shown on the left of this figure. It carries complementary hydrogen bonding sites for two molecular pieces. As a result of hydrogen bonding, the two partners are ideally aligned so that they can react to form a covalent bond. Breaking of the hydrogen bonds with the template would release the daughter molecule and let the template carry on the catalysis. In the extreme example in which the template and the daughter are the same, the molecules effectively self-replicate.

Hydrogen Bonding and New Materials

The planned growth of hydrogen bonds in two dimensions can lead to materials with interesting shapes. The first example shown in *Figure 7* corresponds to a collection of identical molecules held together by hydrogen bonds. The strategic location of the interaction sites allows the formation of a two-dimensional sheet. Additional interactions between the benzene rings on adjacent sheets (through a different type of non-covalent interaction) result in a

Hydrogen bonds in the hands of a practical dreamer can open up infinite possibilities.



stack. Overall, a porous structure with interlocking columns is obtained.

Another example of a sheet-like structure resulting from hydrogen bonds is given in *Figure 8*. Here two different molecules,

Figure 7 (top left) Rigid 'washers' held together by hydrogen bonds in a two-dimensional sheet.

Figure 8 (top right) A beautiful 2D array of H-bonds produced from two components.

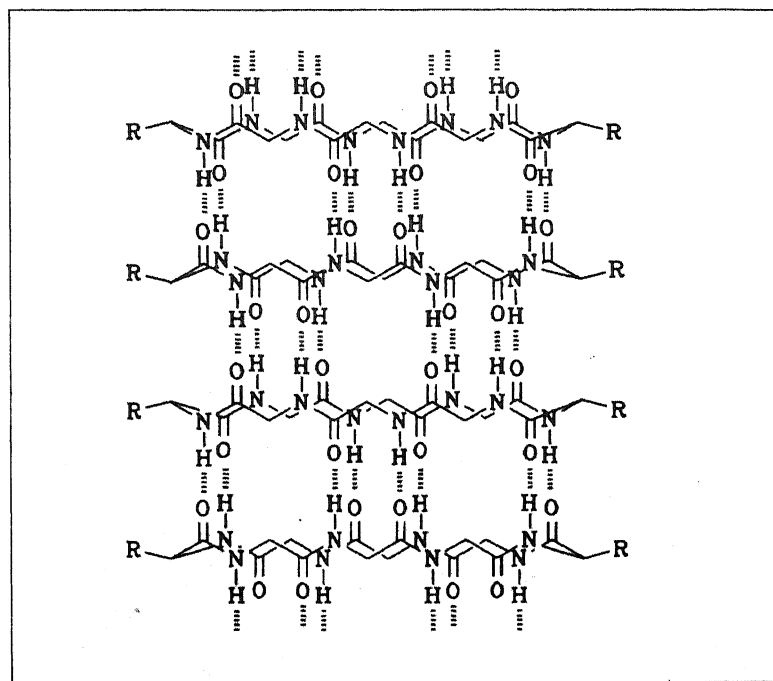


Figure 9 A tubular assembly through H-bond.

Hydrogen bonding has transformed mundane molecules to potential information storage systems, sieves, catalysts, etc.

cyanuric acid and melamine, with complementary hydrogen bonding sites arrange themselves in a beautiful architecture.

In *Figure 3*, the α -helix is characterised by a sequence of parallel hydrogen bonds within the molecule along the helix axis. Other variations are possible, e.g., by mixing parallel and antiparallel arrangements of hydrogen bonds. A lovely example of a structure resulting from intermolecular hydrogen bonding with this type of directional character is shown in *Figure 9*. The tubular assembly has been demonstrated by X-ray crystallography. Such peptide-based nanotubes can transport small molecular or ionic fragments, such as water, ammonia and proton. Hydrogen-bonding directed recognition has also been utilized to design new types of liquid crystalline materials by Lehn.

Hydrogen Bonding, the Magical Glue

Hydrogen bonds in the hands of a practical dreamer can open up infinite possibilities. During the past few decades chemists have concentrated on the art of making and breaking very high energy (200-400 kJ/mol) covalent bonds. The edifices built and broken here are as made from concrete! In the present decade, chemists increasingly prefer to have more flexibility. Hydrogen bonding has proved to be very useful in this approach. The ubiquitous glue has transformed mundane molecules to potential information storage systems, molecular switches of all kinds, materials, surfaces, cavities, sieves, catalysts and on and on.

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The Busy Biochemist ... Otto Warburg was one of the great biochemists of the early part of the twentieth century (H A Krebs was one of his many students who won a Nobel Prize). Once he was invited to a ceremonial function to receive an award from the German Government. Warburg asked for the decoration to be sent by mail, for his experiments did not allow him time to leave the laboratory!



Know Your Personal Computer

3. The Personal Computer System Software

S K Ghoshal

This article surveys system software organization in personal computers using the IBM personal computer software. Details of the hierarchical levels of the system software organization are explained.

Introduction

An overview of the system software organization of a PC is given in *Figure 1*. BIOS (basic input output system) is the lowest level of the operating system. It hides the details of the specific motherboard and projects a higher level interface to the physical hardware. MSDOS (microsoft disk operating system), the most common operating system of the IBM PC uses it to run application programs. These programs can be written in any one of a number of high-level languages (HLL) such as Pascal, C, FORTRAN. Each HLL presents the programmer with an abstract view of the computer.

The complex operations supported by a HLL are implemented by a *runtime library (RTL)* specific to that language. The RTL makes calls to the MSDOS operating system so that various tasks may be performed by the IBM PC hardware and BIOS.

Organization of System Software into Levels

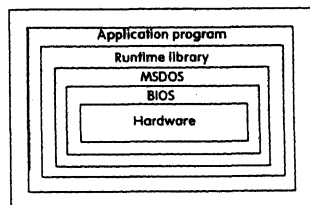
Organizing system software into many hierarchical levels or layers as shown in *Figure 1* gives it the following advantages:

- **Portability:** Programs written using a PC can be moved, compiled and run on any other computer.



Siddhartha Kumar Ghoshal works with whatever goes on inside parallel computers. That includes hardware, system software, algorithms and applications. From his early childhood he has designed and built electronic gadgets. One of the most recent ones is a sixteen processor parallel computer with IBM PC motherboards.

Figure 1 System software of computers are organized in layers like an onion.



Runtime Library

A Runtime Library (RTL) comes with every high level language compiler. It is a collection of large number of subroutines that perform well-defined but complex operations. These operations are needed by every programmer who uses the computer by programming it in the particular high-level language in question. She cannot write each and every detail of how that complex operation is to be done on that given computer. This is because she does not know all the details and does not have all the time needed to understand them before she writes and runs her first program. So the compiler implementor supplies a 'library' of canned programs which our programmer will need. RTL is written by the compiler implementor.

- *Scalability:* The hardware, software and the compilers used to execute an application program can be upgraded to improved versions without having to rewrite or change the program.
- *Modularity:* Any reconfiguration, upgradation or replacement of the software at any level does not affect its function, overall performance or organization.
- *Easy understanding and documentation:* The working of each program level can be understood and explained without getting into details of other levels.

The major disadvantages of organizing system software in layers are:

- Speed of operation. It slows down the application program execution.
- The full potential of the hardware is not used by an application program.

We will illustrate these points with a simple example. Consider the program in *Figure 2* which is written in the C programming language. It stores a number as an integer variable and then prints its value in the hexadecimal representation. Note that several advantages are gained by organizing the system software in a hierarchical fashion on IBM PCs as shown in *Figure 1*.

- This program can be run as an application in any general purpose computer with a C compiler.
- To port the program from one machine to another one must recompile it with a C compiler at the destination site and run it thereafter.
- The programmer need not understand the display hardware of the machine, the addresses occupied by it and so on.
- The output need not always be displayed. It may be redirected to a disk file or any other device, by the operating system.
- The programmer need not have any information on the word

```
main ()
{
/* The following statement stores a hexadecimal number in i */
unsigned int i = 0 x 1234ABCD ;
printf ("%x\n", i); /* The statement prints the value stored in i */
}
```

Figure 2 A small C program to store a value in a variable *i* and display it on a video display.

length of the CPU, the storage of the bytes of a word in physical memory and other details of the CPU-memory subsystem.

- The virtual models of the CPU-memory subsystem and display devices as seen by a C programmer are adequate to write portable programs.
- Anyone who knows C can understand what this program does. Enhancing the CPU-memory and the video display subsystems does not affect the semantics¹ of the program.
- Anyone writing the operating system and other system software knows how to use the basic commands to run the program correctly.

On the other hand, such an organization has the following disadvantages:

- Most of the execution time of the program is spent in the *printf* statement. Although only a write operation is needed for the output, the overhead of the *printf* statement is enormous. That is because the system call for an output operation passes through many levels of the system software. The actual write operation to the video memory occurs at the lowest level of the system software. Between any two levels, a unique and elaborate parameter passing protocol must be followed. All these operations consume CPU time and are called *overheads*.
- Even though the video graphics hardware displays millions of shades of colours, the output produced will only be in one colour, the one to which that environment has been set.
- The program writes only at the current cursor position in one

¹ The operation intended to be performed by a computer program is called its semantics. Unlike human languages, the semantics of computer programming languages and programs can never be ambiguous or ill-defined. The semantics of a computer program must be so straightforward that even a computer (which cannot do anything unless told how to do it and does not normally learn by experience or example) can carry it out. And to all computers in the world, it must mean the same thing.

What is Snowing?

A modern video display adapter has its own memory (video RAM) and processor (called display co-processor). If you write directly into the video memory, you may interfere with the display co-processor attempting to read it for producing the necessary red, green, blue or composite video signals. Even though the video RAM has two independent read/write ports, the CPU gets a higher priority when both display processor and CPU try to simultaneously access it. As a result, the display processor does not get the data it needs from the video memory. It thus goes haywire and sends the beam aimlessly, illuminating bright

spots which appear all over the screen. This appears like snow on the screen. BIOS knows many details of the hardware it controls and makes it appear *clothed* and more sophisticated than it actually is. Do not try to control the hardware. Let BIOS handle it. Even MSDOS gets to the hardware via BIOS. Look at *Figure 1* again. MSDOS in turn has its own share of idiosyncracies. So do not talk to MSDOS directly. Ask your RTL to do that. Just write your application in C as I have in *Figure 2*. It will work without your having to know anything about the hardware, BIOS, MSDOS and the RTL of the C compiler.

given window, giving the programmer no control over its absolute location on the two-dimensional video screen.

- The program uses only the default font type and size. This occurs despite the capacity of the display hardware and driver system softwares for supporting various font types and sizes.

The moment one tries to alleviate these difficulties by writing directly into the video memory or directly programming the display controller hardware, the program loses its portability. Thereafter it remains tied to that specific configuration of the video display hardware.

One of the advantages of organising system software in a hierarchical fashion is that the programmer need not understand the display hardware of the machine, the address occupied by it and so on.

In the context of *Figure 1*, let us see how the program given in *Figure 2* is executed.

- The application program of *Figure 2* calls the function *printf*. The program to carry out *printf* is in the runtime library file that comes along with the C compiler. The parameters supplied to *printf* are the 32-bit integer which is a number (in our case 0x1234ABCD) and the print format (in our case %x).
- The runtime library converts the data to be printed into an

Beware of Turbocharging

Many compilers produce a code that directly modifies some internal data structures of low-level operating systems and writes into device control registers directly. In other words, the runtime libraries of such compilers, directly call BIOS (the BIOS call can be nonstandard and undocumented) or initialize hardware, bypassing intermediate levels of system software. This is called *supercharging or turbocharging*. The implementors of such compilers have inside knowledge of the IBM PC architecture and BIOS from sources that are not always open. The object code produced by

such compilers runs much faster than the ones produced by portable compilers but has no guarantees. Any upgrade or replacement to the system at any of the levels shown in *Figure 1* may render an old and useful turbocharged code unable to work. Invest your money and ideas on portable compilers. CPUs rapidly get faster over the years. The temporary gain in speed from turbocharging today may be obviated in a couple of years by upgrading. You also risk becoming obsolete in a couple of years if you turbocharge your code.

ASCII string. It then calls the operating system to print the string. In the IBM PC and MSDOS environment, it makes a function call 09 and a system call to the service routine of INT 21H which is part of the code text of the MSDOS operating system.

- MSDOS determines how to perform the output operation. At this stage, it can redirect the output to an open file. In case the output has to be written on the video display device, it calls BIOS by making a system call to the service routine of INT 10H with a function code to display a character at the current cursor position. Typically, it makes as many BIOS calls as there are characters in the string to be displayed.
- BIOS knows the type of the display adapter, the memory addresses of the video RAM and the I/O port addresses of the video controller. Its internal data structure gives the mode in which the video adapter is initialized; so it knows when to scroll the display, perform a carriage return and line feed the cursor. Scrolling is done either by physically moving data in the video RAM by using the CPU, or by setting an appropriate page register in the video display adapter. BIOS can therefore handle the ASCII codes of carriage return and line feed char-

Instructions to obtain services of BIOS and MSDOS

MSDOS is accessed through the software *interrupt* instruction. There are eight different DOS interrupts. One of these, INT 21H, implements 87 different functions which are referred to as the DOS *function calls*. BIOS is also entered using an interrupt. INT 10H is used to enter video-IO routines and use the display of the IBM PC.

Interrupts

Events other than branch and subroutine call instructions which alter the normal sequential flow in a program are called *interrupts*. Four major types are: requests for attention by I/O devices, invoking operating system service from a user program (service call) and errors such as arithmetic overflow/underflow using undefined instruction. There is no uniform terminology to describe these events. IBM and Intel call all of them *inter-*

rupts, Motorola and the MIPS computer corporation call them *exceptions*, and DEC calls interruptions caused by system calls and error conditions *traps*. Whenever exceptions/interrupts occur the current program is suspended and the control jumps to service the interrupt. The current state of the CPU is saved so that the program can later resume from the point where it was suspended.

acters if they appear in the string to be displayed.

- The text of BIOS is in the EPROM. It writes directly into the video memory producing the desired display.

Similar mechanisms exist in other computer architectures and operating system organizations. BIOS is simpler to understand than some of them.

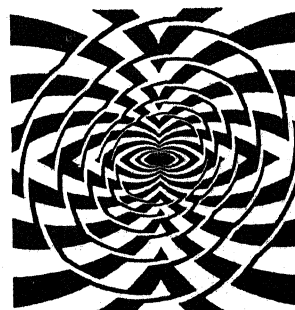
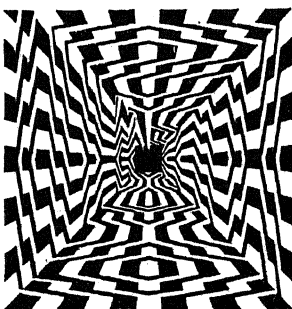
In subsequent articles we will learn more about the system software of the IBM PC. Feel free to write to me if you have any questions or comments about this article.

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Optical illusions ...



The Punctured Plane

How Topology Governs Analysis

Vishwambhar Pati

All loops in \mathbb{R}^2 can be continuously shrunk to a point but there are loops in $\mathbb{R}^2 - (0,0)$ that cannot be; for example, any circle enclosing the origin. This difference in the 'topology' of \mathbb{R}^2 and that of $\mathbb{R}^2 - (0,0)$ results in significant difference in the 'analysis' on these spaces. The main theme of this article is to illustrate how topology governs analysis.

Most of you are probably familiar with analysis, another name for calculus. At its core are the fundamental concepts of limits, differentiation and integration of functions on \mathbb{R} , and more generally \mathbb{R}^n . What is topology? Perhaps some of you have studied metric spaces, and continuous maps between metric spaces. You may be aware that it has to do with Möbius strips, Klein bottles, doughnuts, knots and the like.

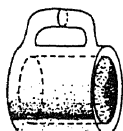
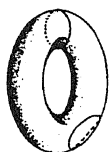
To make a very crude definition, the objective of topology is to study continuity in its utmost generality, and to seek the right setting for this study. The basic objects that topology studies are called *topological spaces*, i.e. sets which have some additional set theoretic structure, governed by some axioms, that enables us to define the notion of a neighbourhood. For example, all the objects listed in the first paragraph are topological spaces. Once this is done, it is easy to define continuity of a map, just as one does for metric spaces. It turns out that to study continuity, it is not really necessary to have a metric. The axioms for topological spaces are set up so that all our familiar intuitive expectations about continuity are realised. On the other hand, the general-

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What is topology? The objective of topology is to study continuity in its utmost generality, and to seek the right setting for this study.



In this article, I hope to give you a flavour of how a topological invariant called homology governs the solvability of a problem in calculus.



A topologist has been defined to be a mathematician who can't tell the difference between a doughnut and a cup of coffee!

ity achieved by ridding ourselves of a metric is so powerful that topology permeates all of mathematics. A continuous map between topological spaces which has a continuous inverse is called a *homeomorphism*. One would like to classify topological spaces upto homeomorphism (i.e., without distinguishing spaces which are homeomorphic), just as one would like to classify, say, groups upto isomorphism. For example, a doughnut is homeomorphic to a coffee cup. A property, such as connectedness, or compactness, which is preserved under homeomorphism, is called a *topological invariant*. In this article, I hope to give you a flavour of how a topological invariant called *homology*, which we shall define, governs the solvability of a problem in calculus. For starters, let us review some *several variable calculus*.

Statement of the Problem

Let $\mathbf{v}(x, y) = (p(x, y), q(x, y))$ be a smooth vector field on an open subset X of the Euclidean plane \mathbb{R}^2 , i.e. both $p(x, y)$ and $q(x, y)$ are defined on X , and infinitely differentiable as functions on X . Those with a physics background may like to think of \mathbf{v} as an electric field, or the velocity field of a fluid confined to the planar region X . A natural fundamental question which arises is whether there exists a *potential function* for this vector field. In other words, does there exist a smooth function $\phi(x, y)$ on X such that

$$p = \frac{\partial \phi}{\partial x}, \quad q = \frac{\partial \phi}{\partial y} \quad (1)$$

holds identically all over X ? This pair of simultaneous differential equations is often abbreviated as $\mathbf{v} = \nabla \phi$ (read gradient of ϕ , or $\text{grad } \phi$).

Let me give you a quick reason as to why it is useful to have a potential function. It is easier to perform summation (and more generally integration) of potentials, which are scalar valued functions, rather than vector fields. If one

has, for example, a line of charge, then to find the electric field at a point you would have to take field contributions of 'infinitesimal' bits of the line, take the components along, say the x-axis, and then integrate. For the potential, you do not need to take components, but simply integrate the potential contributions. The other reason, which is of more interest to us here, is the matter of 'work done' in moving along a smooth path γ . Let $\gamma : [0, 1] \rightarrow X$, where $\gamma(t) = (\gamma_1(t), \gamma_2(t))$ be a smooth function of $t \in [0, 1]$. γ is called a *smooth path* joining $P = \gamma(0)$ to $Q = \gamma(1)$. The work done along γ in the field \mathbf{v} is the *line integral* defined by :

It is easier to perform summation of potentials, which are scalar valued functions, rather than vector fields.

$$\begin{aligned} \int_{\gamma} \mathbf{v} &= \int_0^1 \left(\mathbf{v}(\gamma(t)) \cdot \frac{d\gamma}{dt} \right) dt \\ &= \int_0^1 \left(p(\gamma(t)) \frac{d\gamma_1}{dt} + q(\gamma(t)) \frac{d\gamma_2}{dt} \right) dt \end{aligned} \quad (2)$$

where ' \cdot ' denotes the dot product in \mathbb{R}^2 . Clearly, if a potential function ϕ exists on X , satisfying (1), then the line integral of \mathbf{v} along γ becomes

$$\begin{aligned} \int_{\gamma} \mathbf{v} &= \int_0^1 \frac{d\phi(\gamma(t))}{dt} dt = \phi(\gamma(1)) - \phi(\gamma(0)) \\ &= \phi(Q) - \phi(P) \end{aligned} \quad (3)$$

by the fundamental theorem of calculus. To sum up, the work done along a path is just the difference of the values of the potential function at the *end points* of the path, and *independent* of the path. Thus no line integrals need be calculated to compute the work done. Also, in particular, the work done in moving along a smooth *loop* (i.e. a path γ satisfying $\gamma(1) = \gamma(0)$) is zero !

Another obvious consequence of the existence of a solution to (1) is the following: since ϕ is to be smooth on the open set X , one must have

$$\frac{\partial q}{\partial x} = \frac{\partial^2 \phi}{\partial x \partial y} = \frac{\partial^2 \phi}{\partial y \partial x} = \frac{\partial p}{\partial y} \quad (4)$$



all over X . The (also smooth) function $\frac{\partial q}{\partial x} - \frac{\partial p}{\partial y}$ is called the *curl* of \mathbf{v} , and denoted $\text{curl } \mathbf{v}$. The discussion above shows that a *necessary condition* for (1) to have a solution is that $\text{curl } \mathbf{v} = 0$ identically on X (recall the statement ‘curl grad is zero’, from multivariate calculus). So, for example, the vector field $\mathbf{v}(x, y) = (xy, xy)$ on $X = \mathbb{R}^2$ has no potential function since its curl is not identically zero.

It is quite natural to ask whether $\text{curl } \mathbf{v} = 0$ is a *sufficient* condition for a smooth vector field \mathbf{v} on X to have a potential function satisfying (1). The rest of this note is essentially devoted to this question.

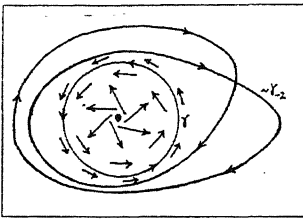


Figure 1 The whirlpool vector field.

For a start, let us consider the simplest case $X = \mathbb{R}^2$. In this case, the answer turns out to be yes. Indeed, define the function ϕ by

$$\phi(x, y) = \int_0^x p(t, 0) dt + \int_0^y q(x, s) ds \quad (5)$$

That this function satisfies (1) is an easy application of the fundamental theorems of calculus about integrals of derivatives and derivatives of integrals; we leave it as an exercise. So now we have a complete answer for a smooth vector field \mathbf{v} on \mathbb{R}^2 , viz. $\mathbf{v} = \nabla \phi$ for some smooth function ϕ if and only if $\text{curl } \mathbf{v} = 0$. This is a particular instance of the Poincaré Lemma for \mathbb{R}^2 . See the book by Singer and Thorpe for the general statement.

What does topology have to do with all this? To elucidate this point, let us migrate from $X = \mathbb{R}^2$ to the punctured plane $X = \mathbb{R}^2 - (0, 0)$.

Consider the smooth vector field

$$\omega(x, y) = \left(\frac{-y}{x^2 + y^2}, \frac{x}{x^2 + y^2} \right)$$

on $\mathbb{R}^2 - (0, 0)$, which is pictured in Figure 1. Note that this vector field has a singularity at the origin, i.e., there is no

way of extending this field to a smooth vector field on \mathbb{R}^2 . You may like to think of it as the surface of an infinite river with a whirlpool at the origin. It is easy to check that this vector field is curl free on $\mathbb{R}^2 - (0, 0)$, and we may again ask whether there is a smooth potential function ϕ defined on $\mathbb{R}^2 - (0, 0)$ such that $\omega = \nabla\phi$. If there were, then the earlier discussion would imply that its line integral along a loop in $\mathbb{R}^2 - (0, 0)$ would have to be zero. On the other hand, a (hopefully empty!) boat drifting around the whirlpool would certainly go on gaining energy in the counterclockwise direction. Let us verify this (without getting into that boat!). Let $\gamma(t) = (\cos 2\pi t, \sin 2\pi t)$ where $t \in [0, 1]$, be the loop going counter-clockwise once around the puncture (see Figure 1). Then $\omega(\gamma(t)) = (-\sin 2\pi t, \cos 2\pi t)$, $\frac{d\gamma}{dt} = (-2\pi \sin 2\pi t, 2\pi \cos 2\pi t)$, and the line integral of ω along γ is

$$\begin{aligned}\int_{\gamma} \omega &= \int_0^1 ((-\sin 2\pi t)(-2\pi \sin 2\pi t) + (\cos 2\pi t)(2\pi \cos 2\pi t)) dt \\ &= 2\pi \int_0^1 dt = 2\pi\end{aligned}\quad (6)$$

which is certainly non-zero. Hence we have a curl free smooth vector field ω on $\mathbb{R}^2 - (0, 0)$ which is *not* the gradient of any potential function! Making just one puncture in \mathbb{R}^2 has completely changed its analytical nature.

Now I would like to dwell upon the topological characteristic of $\mathbb{R}^2 - (0, 0)$ which ‘causes’ this. It is well known that all loops in \mathbb{R}^2 can be continuously shrunk to a point, but there are loops in $\mathbb{R}^2 - (0, 0)$ that cannot be continuously shrunk to a point. To make all this precise, we need a little bit of ‘technology’.

Some Planar Topology

Let X denote an open subset of \mathbb{R}^2 . A *piecewise smooth path* in X is a map $\gamma : [0, 1] \rightarrow X$ such that (i) γ is continuous,

We can have a curl free smooth vector field ω on $\mathbb{R}^2 - (0, 0)$ which is not the gradient of any potential function! Making just one puncture in \mathbb{R}^2 can completely change its analytical structure.



and (ii) there is a subdivision $0 = a_0 < a_1 < \dots < a_k = 1$ of $[0, 1]$ such that γ is smooth on each of the sub-intervals $I_j = [a_j, a_{j+1}]$. $\gamma(0)$ is called the *initial point* and $\gamma(1)$ the *end point* of γ . The *inverse path* to γ is the path γ^{-1} defined by $\gamma^{-1}(t) = \gamma(1-t)$. We shall now refer to piecewise smooth paths simply as paths, for brevity. As before, a *loop* will mean a path γ whose initial and end points are the same point x . In this case we say the loop γ is *based* at x .

If γ and τ are two paths such that the end point $\gamma(1)$ of γ is the initial point $\tau(0)$ of τ , then one can form the *composite path* $\gamma * \tau$ defined by $\gamma * \tau(t) = \gamma(2t)$ for $0 \leq t \leq \frac{1}{2}$ and $= \tau(2t - 1)$ for $\frac{1}{2} \leq t \leq 1$. (This is the reason for introducing piecewise smooth paths, because the composite of smooth paths need not be a smooth path, but the composite of piecewise smooth paths is piecewise smooth.) In particular, we can compose two loops based at the same point.

The *constant path* c_x at a point $x \in X$ is defined by $c_x(t) = x$ for all $t \in [0, 1]$. Henceforth, we shall always assume that X is a *path connected* open subset of \mathbb{R}^2 , i.e. given any two points P and Q in X , there is a path γ in X with P as its initial and Q as its end point.

Given a smooth vector field $\mathbf{v} = (p, q)$ on X , and a piecewise smooth path γ in X , we can define the line integral

$$\int_{\gamma} \mathbf{v} = \sum_{j=0}^{k-1} \int_{a_j}^{a_{j+1}} \left(p(\gamma(t)) \frac{d\gamma_1}{dt} + q(\gamma(t)) \frac{d\gamma_2}{dt} \right) dt$$

With this definition, and the standard facts about change of variables in integration, it is easy to see that $\int_{\gamma * \tau} \mathbf{v} = \int_{\gamma} \mathbf{v} + \int_{\tau} \mathbf{v}$ and $\int_{\gamma^{-1}} \mathbf{v} = -\int_{\gamma} \mathbf{v}$. Also, for the constant path c_x at x , we have $\int_{c_x} \mathbf{v} = 0$.

One is now equipped to do some algebra with (piecewise smooth) loops. Let X be a path-connected open subset of

\mathbb{R}^2 , as before. I would like to define an equivalence relation on loops in X as follows. Say that the loops γ and τ are *equivalent* (or *homologous*, or *freely homotopic*) if there exists a piecewise smooth map $F : [0, 1] \times [0, 1] \rightarrow X$ such that (i) $F(t, 0) = \gamma(t)$, $F(t, 1) = \tau(t)$ for all $t \in [0, 1]$, (ii) $F(0, s) = F(1, s)$ for all $s \in [0, 1]$. Such a map is called a (free) *homotopy*. We write $\gamma \sim \tau$ to denote that γ is equivalent to τ . You should verify that this is an equivalence relation.

One intuitively thinks of $\gamma_s = F(\cdot, s)$ as a continuous one parameter family of loops evolving from γ at $s = 0$ to τ at $s = 1$. Finally, given a loop γ in X , and an arbitrary point $x \in X$, there is a loop $\tilde{\gamma}$ which is equivalent to γ , and which is based at x . For, take a fixed path σ joining x to $y = \gamma(0) = \gamma(1)$, which is possible by the path connectedness of X . Define $\tilde{\gamma} = \sigma * \gamma * \sigma^{-1}$. Figure 2 should enable you to construct a homotopy. Because of this, one can compose equivalence classes of loops. If γ and τ represent two equivalence classes, the above remark allows us to assume without loss of generality that γ and τ are based at the same point, and we may define $\gamma + \tau$ to be the equivalence class of the loop $\gamma * \tau$. We will omit the proof that this operation is well-defined, i.e. that $\gamma \sim \gamma'$, $\tau \sim \tau'$ implies $\gamma * \tau \sim \gamma' * \tau'$, though it isn't difficult to prove this, by 'pasting homotopies'. The notation '+' is meant to indicate that the operation is abelian, and it is not difficult to show that $\gamma * \tau$ and $\tau * \gamma$ are equivalent. If γ is a loop with $\gamma(0) = \gamma(1) = x$, you may verify, for example, that $\gamma * c_x \sim \gamma \sim c_x * \gamma$. Also, $\gamma * \gamma^{-1} \sim c_x \sim \gamma^{-1} * \gamma$. Thus, the equivalence class of the constant loop (at any point) is the identity element, and the inverse of (the equivalence class of) γ is (the equivalence class of) the loop γ^{-1} . For notational simplicity, we shall denote a loop and its equivalence class by the same letter, say, γ , τ , etc.

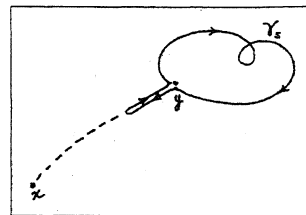


Figure 2 Moving loops around.

The abelian group of these equivalence classes of loops in



X is a very important one, and is called the *first homology group* of X , and denoted $H_1(X)$. It was essentially invented by Poincaré and Riemann for their study of Riemann surfaces.

I claim that the distinction between the Euclidean plane \mathbb{R}^2 and the punctured plane $\mathbb{R}^2 - (0,0)$ is detected by the first homology group. First, let us see that $H_1(\mathbb{R}^2)$ is the trivial group $\{0\}$. This is because the homotopy

$$F(t, s) = (1 - s)\gamma(t)$$

makes any loop γ equivalent to the trivial loop, so there is only the equivalence class of the constant loop in $H_1(\mathbb{R}^2)$, which therefore is the trivial group! In fact, this argument shows that the first homology group of any convex (in fact any starlike) open subset of \mathbb{R}^2 is trivial. For more on H_1 , see the Greenberg lectures on algebraic topology or the book by Bott and Tu.

Of course, $\mathbb{R}^2 - (0,0)$ is not convex, or starlike, and one would like to compute its first homology group. First, let me try to convince you that it is non-trivial. For this, we will need the following lemma, which is the crucial bridge between topology and calculus.

Let X be a path connected open subset of \mathbb{R}^2 , and \mathbf{v} be a curl free smooth vector field on it. Then, for two loops γ and τ in X such that $\gamma \sim \tau$, we have $\int_\gamma \mathbf{v} = \int_\tau \mathbf{v}$.

To see this, first let us make the simplifying assumption that both γ and τ are smooth, and that the homotopy $F : [0, 1] \times [0, 1] \rightarrow X$ between them, satisfying $F(t, 0) = \gamma(t)$, $F(t, 1) = \tau(t)$, is also smooth. We let σ denote the path defined by $\sigma(s) = F(0, s) = F(1, s)$. Write $F(t, s) = (F_1(t, s), F_2(t, s))$ in terms of its component functions. Write $\mathbf{v}(x, y) = (p(x, y), q(x, y))$, and for brevity let us denote partial differentiation by subscripts e.g. $p_y = \frac{\partial p}{\partial y}$, $F_{1,s} = \frac{\partial F_1}{\partial s}$

The distinction between the Euclidean plane \mathbb{R}^2 and the punctured plane $\mathbb{R}^2 - (0,0)$ is detected by the first homology group.

etc. We will use the smooth homotopy F to 'pullback' the vector field \mathbf{v} from X to a smooth vector field \mathbf{w} on the square $[0, 1] \times [0, 1]$. More precisely, $\mathbf{w}(t, s) = (\tilde{p}(t, s), \tilde{q}(t, s))$ where :

$$\begin{aligned}\tilde{p}(t, s) &= p(F(s, t))F_{1,t} + q(F(s, t))F_{2,t} \\ \tilde{q}(t, s) &= p(F(s, t))F_{1,s} + q(F(s, t))F_{2,s}\end{aligned}$$

This seems a bit concocted, but is got from substituting $F_1(t, s)$ for x , $F_2(t, s)$ for y in the 'differential' $p dx + q dy$, and reading the coefficients of dt and ds in the resulting differential. Using the chain rule, one directly computes

$$\begin{aligned}\text{curl } \mathbf{w}(t, s) &= (\tilde{q}_t(t, s) - \tilde{p}_s(t, s)) \\ &= (q_x(F(t, s)) - p_y(F(t, s))) (F_{1,t}F_{2,s} - F_{1,s}F_{2,t}) \\ &= 0\end{aligned}$$

since \mathbf{v} curl free implies $q_x - p_y = 0$. Thus this new vector field \mathbf{w} on $[0, 1] \times [0, 1]$ is also curl free. Now, by Green's Theorem, (see page 134 of Spivak's book), we have

$$\begin{aligned}0 &= \int_{[0,1] \times [0,1]} (\tilde{q}_t - \tilde{p}_s) dt ds \\ &= \int_0^1 \mathbf{w}(t, 0) dt + \int_0^1 \mathbf{w}(1, s) ds + \int_1^0 \mathbf{w}(t, 1) dt + \int_1^0 \mathbf{w}(0, s) ds \\ &= \int_{\gamma} \mathbf{v} + \int_{\sigma} \mathbf{v} - \int_{\tau} \mathbf{v} - \int_{\sigma} \mathbf{v} \\ &= \int_{\gamma} \mathbf{v} - \int_{\tau} \mathbf{v}\end{aligned}$$

where the second line is the line integral of \mathbf{w} along the boundary of the square, and the third line follows by substituting the definition of \mathbf{w} and change of variables. (If you want to avoid Green's theorem, use the fact that \mathbf{w} is curl free on $[0, 1] \times [0, 1]$ implies the existence of a potential function ψ constructed exactly as we did for \mathbb{R}^2 in (5). Then the second equation above is true since the line integral of \mathbf{w} on the closed loop defined by the (counterclockwise) boundary of $[0, 1] \times [0, 1]$, will have to be zero, by (3).)

A two-dimensional analogue of the fundamental theorem of integral calculus expresses a double integral over a planar region, R , as a line integral taken along a path determined by the boundary of R whenever the integrand is a partial derivative. This result is usually attributed to G Green and is known as Green's theorem. In fact it appeared earlier in the work of Lagrange and Gauss.



For the more general piecewise smooth situation, one subdivides the square $[0, 1] \times [0, 1]$ into small subsquares on each of which the homotopy is smooth, and replaces the integral of curl \mathbf{w} on each subsquare by a line integral of \mathbf{w} on its boundary. Adding up for all these subsquares, the line integrals on all the internal edges cancel pairwise, and what remains in the end, as before, is the line integral of \mathbf{w} on the boundary of $[0, 1] \times [0, 1]$. This proves the lemma.

Solution of the Problem

To get back to our story now, let us review the opening discussion about solving (1) for \mathbf{R}^2 in the light of homology. Note that since every loop in \mathbf{R}^2 is equivalent to the *constant loop* or *trivial loop*, the lemma above implies that the line integral of a curl free vector field along any loop is equal to the line integral around the constant loop, which is zero. Furthermore, if γ_1 and γ_2 are two paths joining the point P to the point Q in \mathbf{R}^2 , $\gamma = \gamma_1 * \gamma_2^{-1}$ is a loop based at P , so $0 = \int_{\gamma} \mathbf{v} = \int_{\gamma_1} \mathbf{v} - \int_{\gamma_2} \mathbf{v}$ for a curl free field \mathbf{v} , which implies that the work done along a path in a curl free field depends *only on the end-points* of the path. This is precisely the statement (3). Thus for a curl free \mathbf{v} on \mathbf{R}^2 , we may define the potential function $\phi(x, y) = \int_{\gamma} \mathbf{v}$ where γ is *any path* joining a predetermined point P to the moving point $Q = (x, y)$. We chose one such path in (5), but could have chosen any other.

On the other hand, for $\mathbf{R}^2 - (0, 0)$, we have the curl free (whirlpool) vector field ω introduced earlier, whose integral along the loop $\gamma(t) = (\cos 2\pi t, \sin 2\pi t)$ is non-zero. So the lemma above implies, in particular, that *this loop cannot be equivalent to the trivial loop !*

In other words, the homology group $H_1(\mathbf{R}^2 - (0, 0))$ is non-trivial.



In fact, if we consider the loops $\gamma_n(t) = (\cos 2\pi nt, \sin 2\pi nt)$ for $n \in \mathbf{Z}$, we see that $\int_{\gamma_n} \omega = 2\pi n$, so that γ_n cannot be equivalent to γ_m for $n \neq m$. Thus the first homology group of $\mathbf{R}^2 - (0, 0)$ is at least as large as the group of integers.

In fact, it turns out (though the proof is quite non-trivial) that the first homology of the punctured plane $H_1(\mathbf{R}^2 - (0, 0)) \simeq \mathbf{Z}$, with the loop γ_n introduced above representing the integer n . So every loop γ in $\mathbf{R}^2 - (0, 0)$ is equivalent to some γ_n , and in view of the preceding lemma, this integer n is determined by the relation $2\pi n = \int_{\gamma} \omega$. The integer n is called the *winding number* of γ about $(0, 0)$. For the snaky loop in *Figure 1*, for example, the winding number is -2 . For more on this fascinating topic, and the connections with complex analysis, see chapter 4 of the book by Ahlfors.

To tie up this discussion, it would be very pleasing if instead of throwing up one's hands about the insolubility of (1), one could use the fact that $H_1(\mathbf{R}^2 - (0, 0)) \simeq \mathbf{Z}$ to give a quantitative answer regarding (1). For this we will use a very beautiful theorem, which is due to Georges de Rham. Note that our foregoing lemma says that for X a path connected open subset of \mathbf{R}^2 , the line integral $\int_{\gamma} \mathbf{v} = 0$ for a curl free field \mathbf{v} on X if γ is equivalent to a constant loop in X . (In fact, this is a reformulation of the lemma).

The de Rham theorem (in this particular situation) asserts the following: If for a curl free vector field \mathbf{v} we have that $\int_{\gamma} \mathbf{v} = 0$ for *all loops* γ in X , then $\mathbf{v} = \nabla \phi$ for some smooth function ϕ on X .

Now let \mathbf{v} be a curl free vector field on $\mathbf{R}^2 - (0, 0)$. Compute the line integral $\int_{\gamma_1} \mathbf{v}$, where $\gamma_1(t) = (\cos 2\pi t, \sin 2\pi t)$ is the generating loop for $H_1(\mathbf{R}^2 - (0, 0))$. This will be some real number α , say. Since $\int_{\gamma_1} \omega = 2\pi$, where ω is the whirlpool

vector field, it follows that

$$\int_{\gamma_1} \left(\mathbf{v} - \frac{\alpha}{2\pi} \omega \right) = 0$$

Since γ_1 is a generator for $H_1(\mathbb{R}^2 - (0,0))$, and the line integral over a sum of loops is the sum of the line integrals over those loops, it follows that

$$\int_{n\gamma_1} \left(\mathbf{v} - \frac{\alpha}{2\pi} \omega \right) = 0$$

for all $n \in \mathbb{Z}$. Since every loop γ in $\mathbb{R}^2 - (0,0)$ is equivalent to $\gamma_n \sim n\gamma_1$ for some integer n , and $\mathbf{v} - \frac{\alpha}{2\pi} \omega$ is curl free, it follows that $\int_{\gamma} \left(\mathbf{v} - \frac{\alpha}{2\pi} \omega \right) = 0$ for every loop γ in $\mathbb{R}^2 - (0,0)$. Thus, by de Rham's theorem, we have $\mathbf{v} - \frac{\alpha}{2\pi} \omega = \nabla \phi$ for some smooth function ϕ on $\mathbb{R}^2 - (0,0)$.

So the final answer is : If \mathbf{v} is a vector field on $\mathbb{R}^2 - (0,0)$ such that $\text{curl } \mathbf{v} = 0$, then there exists a real number λ and a smooth function ϕ on $\mathbb{R}^2 - (0,0)$ such that $\mathbf{v} = \lambda \omega + \nabla \phi$, where $\lambda = 1/2\pi \int_{\gamma_1} \mathbf{v}$ and ω is the whirlpool vector field. So we have 'measured' exactly how far we are from the solvability of (1).

Another algebraic way of saying the same thing is as follows. Denote, for X as above, the \mathbb{R} -vector space of curl free vector fields on X by $Z^1(X)$. In this vector space, there sits the vector subspace of all vector fields which are gradients of potential functions, and this subspace is denoted $B^1(X)$. The quotient space $Z^1(X)/B^1(X)$, which is called the *first de Rham cohomology* of X and denoted $H^1(X)$ is therefore a real vector space which measures how much curl free fields depart from being gradients of functions. For example, the opening discussion showed that $H^1(\mathbb{R}^2) = 0$. What we have seen as the outcome of the entire discussion for $\mathbb{R}^2 - (0,0)$ is that $H^1(\mathbb{R}^2 - (0,0))$ is isomorphic to the one dimensional real vector space \mathbb{R} , and a basis element is, for example, the 'whirlpool' vector field ω .

Suggested Reading

- M Spivak.** *Calculus on Manifolds.* Benjamin. 1965.
- L Ahlfors.** *Complex Analysis.* McGraw Hill. 1966.
- MJ Greenberg.** *Lectures on Algebraic Topology.* Benjamin. 1967.
- I M Singer. J A Thorpe.** *Lecture Notes in Elementary Topology and Geometry.* Springer UTM. 1967.
- R Bott. L Tu.** *Differential Forms in Algebraic Topology.* Springer GTM 82. 1982.

More generally, for X as above, given a de Rham cohomology class represented by a curl free field \mathbf{v} , we get a natural abelian group homomorphism $\theta_{\mathbf{v}} : H_1(X) \rightarrow \mathbb{R}$, which takes the homology class of a loop γ to $\int_{\gamma} \mathbf{v}$. That this map $\mathbf{v} \rightarrow \theta_{\mathbf{v}}$ is well defined follows from the foregoing discussion. The full force of the de Rham theorem is: This map $\theta : H^1(X) \rightarrow \text{hom}_{\mathbb{Z}}(H_1(X), \mathbb{R})$ is an isomorphism of \mathbb{R} -vector spaces. The symbol on the right side denotes abelian group homomorphisms, and it is an \mathbb{R} vector space via point-wise scalar multiplication. For a proof, see the book by Bott and Tu or the book by Singer and Thorpe.

Finally, the first homology group $H_1(X)$ can be defined using *continuous* loops and homotopies, instead of piecewise smooth loops and homotopies. Certain approximation theorems say that the homology remains unchanged. This clearly makes $H_1(X)$ a topological invariant. The de Rham theorem therefore asserts that the vector space $H^1(X)$, which is a purely analytical object governing the solvability of a system of first order partial differential equations, is in fact a topological invariant. So, for example, if you took any open starlike subset of \mathbb{R}^2 , and punched out a closed disc contained in its interior, the space you'd get has the same first de Rham cohomology as the punctured plane! In particular, the above analysis of curl free fields on $\mathbb{R}^2 - (0, 0)$ applies to such a space.

The reader may want to guess what happens to homology and de Rham cohomology for $X = \mathbb{R}^2 - F$, where F is a finite set of points. I urge you to try. I also leave you with a drawing (*Figure 3*) of the torus that you may want to analyse.

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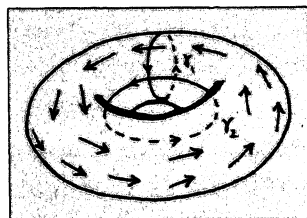


Figure 3 *The torus*

Nature Watch

The Ancient Mariners

Kartik Shanker



Kartik Shanker was involved with the conservation of the Olive Ridley with the Students Sea Turtle Conservation Network (SSTCN) in Madras. Thereafter, he spent two years in the Upper Nilgiris studying small mammal and herpetofaunal communities, a subject in which he hopes to acquire a Ph.D in the near future.

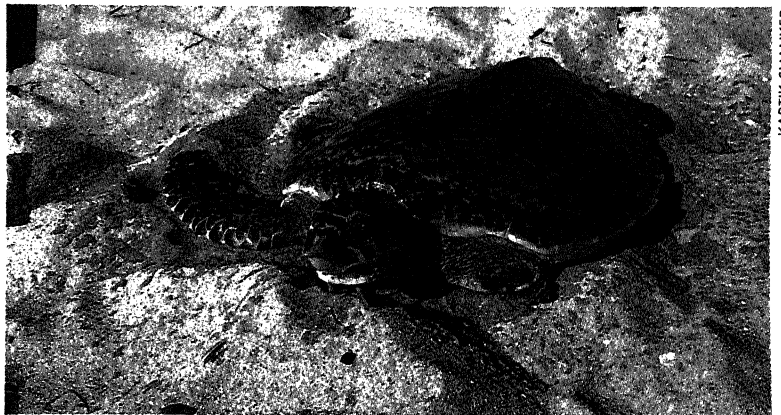
Sea turtles are a fascinating group of marine reptiles that evolved millions of years ago. They show an intriguing variety of strategies to deal with their aquatic mode of life. Their migrations are legendary, and the mass nesting of the Ridelys is one of nature's most extraordinary spectacles. The eight species are all endangered due to human activities. While some have been exploited for meat, others have suffered due to factors such as pollution. This article details some of the more interesting aspects of their life history and examines their decline in recent times.

An Eggstravaganza

Imagine. There are hundreds of eggs flying through the air and the beach is thick with thousands of turtles; some are moving around laboriously searching for a place to nest; others are digging up the sand and, with it, the nests of previous turtles; eggs, yolk and sand are flung with abandon; some are stone still, laying a hundred eggs or more into painstakingly excavated nests; and yet others are thumping the sand in a peculiar dance before

Sea turtles are reptiles which have adapted to an aquatic life.

Figure 1 A dead Hawksbill turtle; its pretty carapace is used for making 'tortoise shell' articles like spectacles and combs.



KARTIK SHANKER

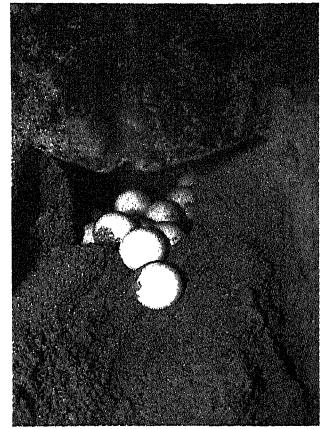
crawling back and disappearing into the blackness of the sea. Early next morning, the beach is deserted and silent, covered with a carpet of eggs, a seemingly senseless and futile waste.

Bizarre and fantastic as this sounds, it actually happens. This is nature's little madness, her extravaganza of eggs, known to turtle biologists as an *arribada* or mass nesting. There is meaning behind the madness, and the protagonist of this spectacular drama is the Olive Ridley sea turtle.

Sea Turtles of the World

The Olive Ridley is one of eight species of sea turtles. It is one of the smallest, measuring about 2 feet and weighing 40-50 kg. The largest is the Leatherback, growing upto 8 feet in length and weighing 600- 700 kg. The other sea turtles are the Green turtle, famous for turtle soup, the Hawksbill, known for its pretty shell, the Loggerhead, the Australian Flatback, the Black turtle and the Kemp's Ridley. Five of these are found in Indian waters: the Olive Ridley, the Leatherback, the Loggerhead, the Green turtle and the Hawksbill (see *Figures 1,2,3*). The Olive Ridley is the most common and nests all along the Indian coastline.

Sea turtles are reptiles (ie. cold blooded lung breathing vertebrates) which have adapted to an aquatic life. They are believed to have evolved more than a hundred million years ago with the dinosaurs. Their ancestors were land living reptiles which in turn had descended from sea living animals. The great advantage that reptiles had over amphibians is that they could lay their eggs on land; their eggs – called amniotic eggs – had their own aquatic



KARTIK SHANKER

Figure 2 An Olive Ridley lays 100-150 eggs in her nest ; the soft shelled eggs are about the size of ping pong balls.

Figure 3 (bottom left) The Leatherback is the largest of the sea turtles ; it is also different from the others in that it has a soft shell, made of cartilage.

Figure 4 (bottom right) The Olive Ridley is the smallest sea turtle ; it is found all over the world and nests all along the Indian coastline.



SATISH BHASKAR



KARTIK SHANKER

environment, the amniotic fluid. This very adaptation was to prove almost fatal to sea turtles many million years after their evolution.

Never the Same Flipper

Though sea turtles have adapted to sea living in every way, they still have to come ashore to lay their eggs. After mating, which takes place in the sea, the female crawls 10 - 20 metres above the high water mark and finds a suitable site. Then, after clearing away surface sand, she excavates a flask shaped nest with her hind legs. All aquatic turtles do this, but sea turtles unfailingly use their hind flippers alternately; freshwater turtles are not so particular. Archie Carr, a famous turtle biologist, even suggested that a sea turtle could be defined as a turtle that never put the same flipper into its nest hole twice in succession. There is an anecdotal account of a loggerhead which had one hind flipper missing. When this turtle nested, the side with the missing flipper always made a token gesture of removing sand. This is believed to be indicative of the degree of genetic programming in the behaviour of the turtle.

Once the two - feet
deep nest has
been excavated,
the turtle lays
100-150 eggs in the
hole and covers it
with sand.

Once the two feet deep nest has been excavated, the turtle lays 100-150 eggs in the hole and covers it with sand. Some of the species like the Ridley thump the sand down with rocking movements of their body. The turtle then returns to the sea. Most of the species have specific breeding seasons. They also have distinct breeding and feeding grounds, which may be several thousand kilometres apart. This is because the beaches that favour nesting may not be rich in their food resource (see *Figure 4*).

Before and After the Lost Year

Once the female turtle lays her eggs, she returns to her feeding ground, though she may nest more than once in the same season. There is a myth that the female waits offshore for her hatchlings, but there is absolutely no parental care in sea turtles. The eggs are incubated by the heat of the sun and their own metabolism. After

about 50 days under the sand, they hatch simultaneously and the hatchlings break out using their 'egg tooth'. After hatching, they move about vigorously, and as the nest collapses, they emerge all at once. This ensures that at least a few will escape predators. They usually emerge at night and locate the sea by the bright horizon. Once in the water, they swim frantically using their stored resources till they are past the breakers and then begin using other cues such as wave direction.

Hatchlings fall prey to crabs, birds and small mammals even before they reach the sea. Thereafter, years of peril await them as all kinds of large fish feast on them.

While hatchlings are largely carnivorous in their diet, they are believed to convert partly or wholly to a herbivorous diet consisting largely of seaweeds and algae. Loggerheads seem to have a preference for shellfish, while Leatherbacks feed almost exclusively on jellyfish. Green turtles, due to a predominantly vegetarian diet, may take 30 or more years to mature, but Olive Ridleys mature in 5 to 8 years.

Till recently, scientists had no idea what happened to these hatchlings during what was known as the 'lost year' — they were only seen again when they were the size of dinner plates. Recently, however, hatchlings have been seen floating along in seaweed rafts. The hatchlings are believed to return eventually to the feeding grounds of their parent population. There is also reason to believe that when they mature, these turtles return to breed in the same beaches, where they hatched many years earlier. The survival rate of hatchlings to adulthood is very low, and less than one in a thousand may survive.

Finding the Ascension

Turtles display a remarkable ability to locate the same nesting beach year after year. In some instances, their powers of navigation are truly astounding.

There is a myth that the female waits offshore for her hatchlings, but there is absolutely no parental care in sea turtles. The eggs are incubated by the heat of the sun and their own metabolism.

Turtles display a remarkable ability to locate the same nesting beach year after year.

For example, the green turtle off the coast of Brazil nests in the Ascension islands in the Atlantic. The Ascension islands are a speck in the middle of the ocean and the ability of the turtles to locate them is remarkable. In fact, in the second world war, the pilots crossing the Atlantic had to refill at Ascension, and they had a saying “if you miss the Ascension, your wife gets a pension.” Early tagging studies demonstrated that the same turtles returned to Ascension year after year. DNA studies have shown that this population was distinct from other green turtle populations, strengthening the claim that they show high site-fidelity, and also that the turtles were returning to the same beaches where they hatched.

Scientists have debated for years about the mechanisms that turtles use to navigate. Investigations show that turtles possess both map and compass sense. They are believed to use geomagnetic and chemosensory cues and ocean swells in the course of migrations that cover thousands of kilometres through the open sea.

Arribadas and Deep Sea Diving

The Olive and the Kemp’s Ridley are unique for their arribadas or mass nesting. Hundreds of thousands of turtles migrate together and nest at a particular beach year after year at the same time. There is one arribada nesting beach in Orissa at Gahirmatha. In a 10 km stretch of beach, several hundred thousand turtles nest each year within the space of 2 weeks in February or March, and

SATISH BHASKAR



Figure 5 During an 'arribada', as many as 50,000 Ridleys may nest in a single night on a short stretch of beach.

as many as 50,000 turtles may nest in a single night (*Figure 5*).

Turtles are beautifully adapted to life in the water, with their long flippers and streamlined bodies. The turtles' unique metabolism enables them to stay underwater for very long periods, and some are even known to hibernate under water. Marine mammals like the sperm whales and the elephant seals were believed to be the champions of deep sea diving, going down 4000 feet and deeper. But leatherbacks can also dive to depths of 4000 feet and stay there for an hour or more in search of their favourite food —jellyfish. Several adaptations to marine life believed to have evolved in aquatic mammals may actually have evolved millions of years before in sea turtles.

The turtles' unique metabolism enables them to stay underwater for very long periods, and some turtles are even known to hibernate under water.

Temperature Determines Sex

Another interesting aspect of their biology is that the sex of the hatchlings is not determined by chromosomes as it is in most other animals. There is a critical temperature of incubation at which the hatchlings in a clutch are 50 percent male and 50 percent female. Above this temperature, hatchlings develop into females and below it, into males. This has had serious implications in the conservation of sea turtles.

Decline of the Turtles

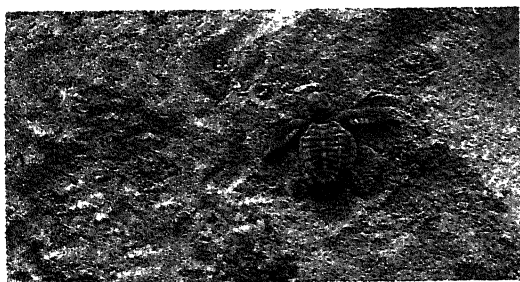
Turtles have long been exploited for various reasons. Green turtles have been caught en masse for their meat (even its name 'Green' is derived from the colour of the meat). Hawksbill shells

Figure 6 (bottom left) Sea turtles have been exploited and killed for various reasons through the centuries.

Figure 7 (bottom right) An Olive Ridley hatchling struggles back to the sea.



KARTIK SHANKER



KARTIK SHANKER

The sex of the hatchlings is not determined by chromosomes, but by the temperature of incubation.

have been used for making tortoise shell products such as combs and spectacles. In fact, in some parts of the world, turtles were heated alive and their shells stripped off as it was believed that the shell would grow back.

The fact that they have to come ashore to lay their eggs has rendered them most vulnerable. The eggs of most species have been poached for consumption. Many adult turtles have been easily killed when ashore. Natural predators like crabs and birds and human induced predators like feral dogs and crows also take their toll on the hatchlings.

Other factors have contributed indirectly to the decline of the turtles. Beach lighting confuses the hatchlings when they emerge from the soil at night. Sand mining and erosion have reduced nesting beaches. Turtles die as incidental catch in large trawl nets (though conscientious trawlers now have 'turtle exclusion devices' which allow the turtles to escape). A number of leatherbacks die by consuming plastic packets mistaking them for jellyfish. Pollution, habitat destruction and other aspects of urbanization have effectively led to the decline of sea turtles.

S.O.S - Save our Sea Turtles

Conservation efforts are on worldwide, to save the sea turtles from extinction (see *Figures 6,7*). Attempts at conservation have largely involved the setting up of hatcheries where eggs are translocated to protect them from poaching and predation. The eggs are incubated in natural conditions or styrofoam boxes and hatchlings are released after the eggs hatch. In India, the Forest Department and NGOs like the Students Sea Turtles Conservation Network (SSTCN) in Madras have conducted conservation programmes.

In some parts of the world, turtles were heated alive and their shells stripped off as it was believed that the shell would grow back.

However, since sex is temperature determined, hatcheries may be tampering with sex ratios in the wild. There has been a shift

to in-situ conservation or beach management where the entire beach is protected. Again, due to human pressure, this has been very difficult in many places since socioeconomic and cultural factors come into play. Conservationists have had to seek compromises between the two methods and the battle to save the sea turtles is far from over. Sea turtles are fascinating denizens of the deep we know so little about and we can little afford to lose such a precious part of the marine world.

Pollution, habitat destruction and other aspects of urbanization have effectively led to the decline of sea turtles.

Suggested Reading

Archie Carr. *So Excellent a Fish: A Natural History of Sea Turtles*. Charles Scribner's Sons. Revised Edition. 1984.

Archie Carr. Rips, Fads, and Little Loggerheads. *Bioscience*. Vol. 36. 92-100. February 1986.

Kenneth J. Lohmann. How Sea Turtles Navigate. *Scientific American*. 100-106. January 1992.

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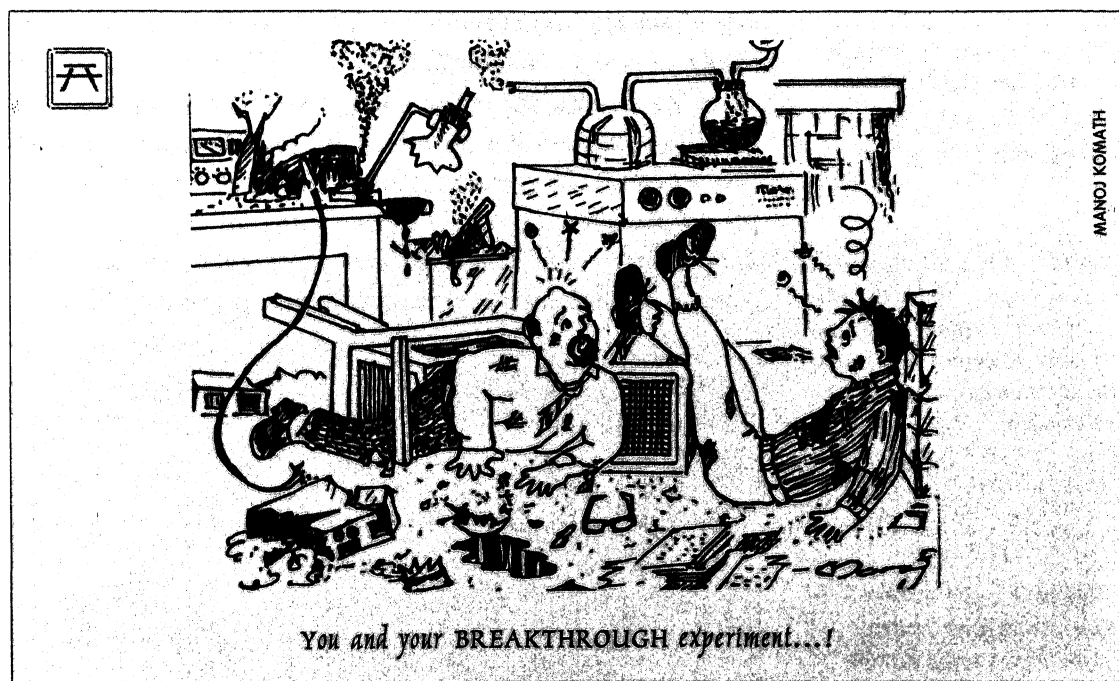
Kartik Shanker

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Molecule of the Month

A Dicopper (II) Complex Hydrolyzes the Phosphate Diester Bond!

R N Mukherjee

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Chemistry at Indian
Institute of Technology,
Kanpur.

A dinuclear copper (II) complex is a synthetic catalyst for modelling enzymatic cleavage of RNA.

¹ DNA: Deoxyribonucleic Acid;
RNA: Ribonucleic Acid; HPNP:
2-Hydroxypropyl-p-nitrophenyl
phosphate; Phosphodiester: Di-
ester of phosphoric acid.

Both DNA and RNA contain phosphodiester linkages in their backbones.¹ The phosphodiester bond is an excellent candidate for this function because of its stability under physiological conditions. However, there are enzymes (nucleases, phosphodiesterases) which can cleave such phosphodiester bonds efficiently. It has been reported that a number of enzymes which hydrolyze phosphate diesters contain two metal ions. Chemists have long been interested in designing synthetic molecules that can mimic or imitate the action of natural enzymes.

Before 1993, compound 1 (*Figure 1*) was only one of a multitude of complexes known to contain two Cu^{2+} ions. However, Chin *et al* (*Angew. Chem. Int. Ed. Engl.*, 1993, 32, 1633) demonstrated that 1 catalyzes the cleavage of the phosphate diester bond present in HPNP (a simple RNA model) under physiological conditions (pH 7, 25°C). The products of this reaction are the cyclic phosphate ester of propylene glycol and p-nitrophenol (*Figure 2*).² Since the latter (in the phenolate form) absorbs radiation of 400 nm, it is rather easy to measure the rate of this reaction. In an

² Note that this transformation is really an intramolecular alcoholysis, rather than hydrolysis. A complete hydrolysis will cleave the cyclic phosphate ester.

Figure 1 Structures of the dinuclear copper (II) catalyst 1 and HPNP

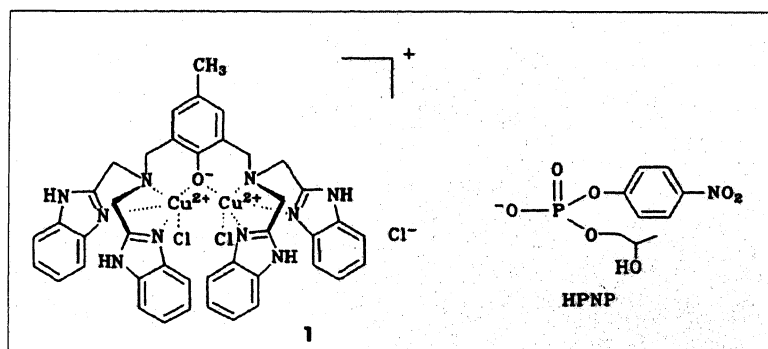




Figure 2 Cleavage products of HPNP

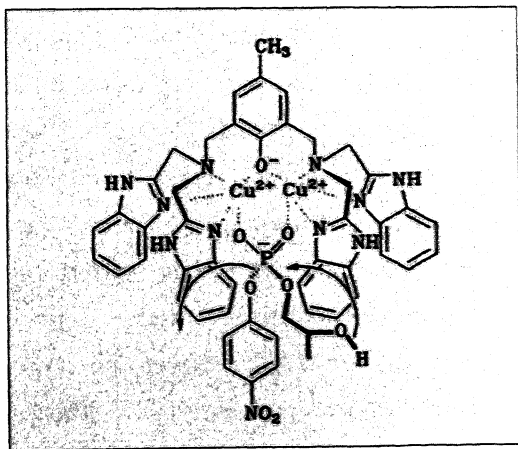
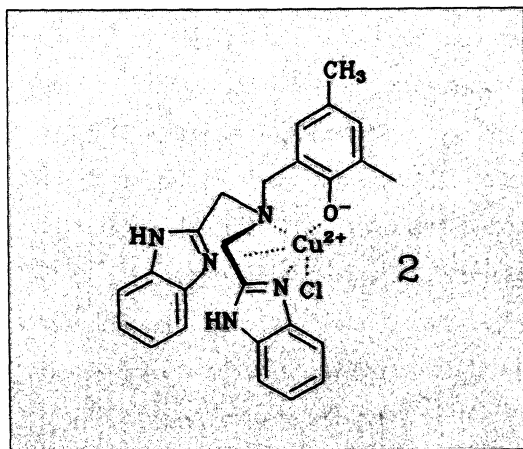
attempt to evaluate the role of the second metal ion in **1**, the mononuclear complex **2** (Figure 3) was also tested for its ability to cleave HPNP. Interestingly, dinuclear complex **1** was found to be almost 50 times more efficient as a catalyst than **2**, suggesting that both the Cu²⁺ ions in **1** cooperate in the catalysis.

The key mechanistic feature of the HPNP cleavage by **1** can be understood as follows. The phosphate group of HPNP binds to the two copper (II) centres of **1** as shown in Figure 4. This activates³ the phosphate ester, or in other words, makes the phosphorus more electrophilic. Subsequently, the internal hydroxyl group attacks the phosphorus atom, and finally *p*-nitrophenolate is liberated. Since the attack of the hydroxyl group increases the charge on the oxygen atoms attached to phosphorus, it is easy to see why compound **1** acts as a better catalyst than **2** (Figure 5). Evidence for the mechanism shown in Figure 4 comes from the analysis of the crystal structure of **1** complexed with dibenzyl phosphate (phosphate replacing the Cl atoms), in which the phosphate was shown forming a bridge between the two Cu²⁺ centers through oxygen atoms.

³ This is an example of Lewis acid activation.

Figure 3 (bottom left) Structure of the mononuclear Cu(II) complex **2**.

Figure 4 (bottom right) Mechanistic feature for double Lewis acid activation for the cleavage of HPNP by **1**.



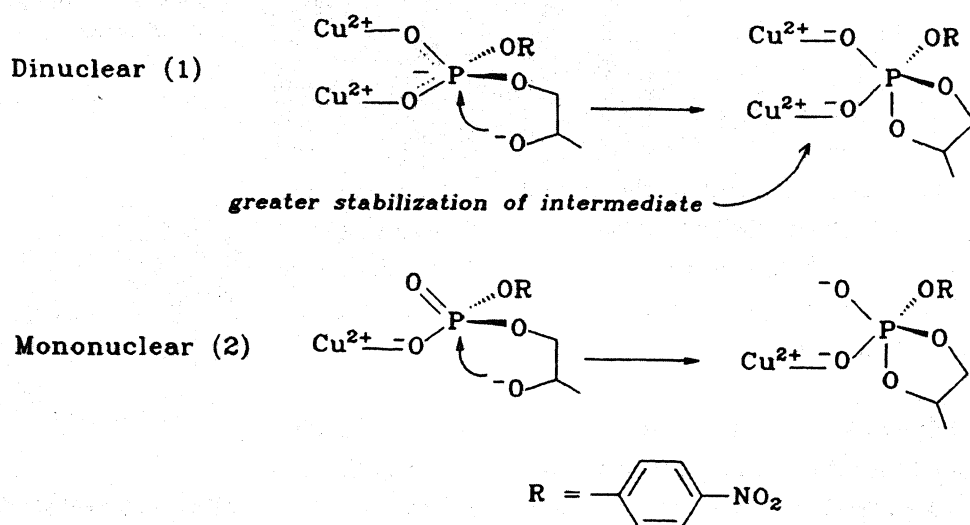


Figure 5 Comparison of the stabilization of the intermediate by 1 and 2.

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Molecules 1 and 2 demonstrate that properly designed synthetic metal complexes can provide valuable information for understanding the chemistry involved in the action of enzymes catalyzing the cleavage of phosphodiester bonds at a molecular level. This kind of biomimetic study can eventually provide subtle insights into the design of more efficient functional nucleolytic agents.



The Second Pauli Principle ... Students in physics and chemistry encounter the Pauli Exclusion Principle (the commonly stated chemistry version: no two electrons in an atom can have the same set of quantum number, including spin; the physics counterpart: total wave functions of fermions are antisymmetric with respect to exchange of any pair of particles). There is also the less well known Second Pauli Principle. This one is simpler. It was widely believed that the presence of Wolfgang Pauli, the Swiss theoretician, in the vicinity of a research laboratory inexplicably caused apparatus to break down. One interpretation is that experimentalists became nervous whenever Pauli entered the laboratory, and consequently made silly mistakes. But what can one say about the explosion which devastated the Physics Department of the University of Berne, which people link to the fact that at that very instant Pauli halted at the Berne railway station on his way to Zurich?

Classroom



In this section of Resonance, we invite readers to pose questions likely to be raised in a classroom situation. We may suggest strategies for dealing with them, or invite responses, or both. "Classroom" is equally a forum for raising broader issues and sharing personal experiences and viewpoints on matters related to teaching and learning science.

! Getting the Facts Right Through Puzzles

The pleasure in science generally comes from the recognition of underlying patterns and unifying principles in diverse phenomena. But before one can appreciate these features, it is necessary to know a large amount of factual information. This is specially so in subjects like chemistry. This feature represents one of the major challenges in the teaching and learning of chemistry, especially at the undergraduate level. Excessive emphasis on memory would turn away students seeking intellectual content in the subject. But the logic of the subject cannot be fully appreciated with a superficial knowledge of chemical facts. Clearly, one needs to strike a balance. There is also plenty of scope for innovation in the classroom.

From J Chandrasekhar, Indian Institute of Science.

G M Kulkarni from Karnatak University, Dharwar, has written to us about an interesting method that students can use to become familiar with chemical symbols. The idea is simple. Take a word like CHEMISTRY. How many elements can be represented using the letters in the word? One can readily spot the elements with one-letter symbols, viz., C, H, I, S and Y. But there are several other elements with two-letter symbols which are contained in the word: Ce, Cm, Cs, Cr, He, Es, Ir, Sc, Se, Sm, Si, Sr, Tc, Th, Te,

Take a word like CHEMISTRY. How many elements can be represented using the letters in the word?



Tm, Ti, Rh, and Re. There are 24 elements (one more, if we accept the name Meitnerium and symbol Mt for element 109) which are contained in the word CHEMISTRY!

The game (assignment?) can have endless variations. We just have to try out a different word. Kulkarni says this type of puzzle worked wonders in her class. The students mastered the symbols of the periodic table and enjoyed the process.

I would like to suggest another puzzle along the same lines for learning about proteins. The naturally occurring amino acids are now represented by one-letter codes (see the poster in *Resonance*, Vol 1, No.1, 1996). Students may be asked to work out the sequence of residues from a word. For example, in this code CHEMISTRY stands for a peptide with 9 residues in the specific sequence: cysteine-histidine-glutamic acid-methionine-isoleucine-serine-threonine-arginine-tyrosine.

It must be noted that the aminoacid code is a restricted alphabet with only 20 letters. Some words can be made, but others not. It is amusing that peptides with the sequence CHEMISTRY, PHYSICS and MATHEMATICS are possible, but there is no peptide called BIOLOGY (There is no amino acid with the code B or O).

From C S Yogananda, Indian
Institute of Science

! McKay's Proof of Cauchy's Theorem on Finite Groups

Cauchy's theorem on
finite groups states
that if a prime p
divides the order of
a finite group G
then there
is an element of
order p in G

The purpose of this note is to present a beautiful proof of Cauchy's theorem on finite groups by J M McKay (*American Mathematical Monthly*, Vol. 66 (1959), page 119). Cauchy's theorem states that if a prime p divides the order of a finite group G then there is an element of order p in G . In fact, McKay's proof shows that there are at least p of them.

To begin with, consider the case of $p = 2$, i.e., when G is of even order. The number of elements in G other than the identity element is odd. Pair off each element other than the identity with its inverse. Since the inverse of an element is

unique and there are an odd number of elements to be paired off, it follows that some elements will have to be paired with themselves; in other words there are elements of order 2.

McKay's proof is a generalisation of this simple proof for the prime 2. Consider the set

$$P = \{ g_1, g_2, \dots, g_p \mid g_i \in G, \prod g_i = e \}$$

where e is the identity element of G . For example, $(e, e, \dots, e) \in P$. The theorem will be proved if we show the existence of a non-trivial *diagonal* element of P , i.e., a p -tuple all of whose entries are the same, say $g \neq e$; g will then be an element of order p . We show the existence of such elements by counting the number of elements of P in two ways. On the one hand, note that we can choose any $p-1$ elements of G and then take the inverse of the product of these $p-1$ elements for the p -th entry. Therefore we have $|P| = n^{p-1}$ where n is the order of G .

We now do the counting by defining an equivalence relation on P . Declare that two p -tuples are related if one of them is a cyclic permutation of the other; in other words, if you think of the elements of each p -tuple to be arranged on a circle then a suitable rotation of one will give the other. It is easy to verify that this is an equivalence relation and hence will give rise to a partition of P .

Exercise: If a p -tuple has at least two of its entries distinct, then all its cyclic permutations, p in number, are distinct. (This is where the fact that p is a prime is used.)

Using the above partition to do the counting we get $|P| = A + B$, where $|P|$ denotes the number of elements in P , A is the number of diagonal elements in P and B is the number of non-diagonal elements in P (p -tuples at least two of whose entries are distinct). We have $|P| = n^{p-1}$ and, by the exercise above, B is a multiple of p . Since p divides n and p divides B it follows that p divides A as well. Thus, to finish the proof, we only have to know that A is not zero; but this follows since $(e, e, \dots, e) \in P$.

Think It Over



This section of Resonance is meant to raise thought-provoking, interesting, or just plain brain-teasing questions every month, and discuss answers a few months later. Readers are welcome to send in suggestions for such questions, solutions to questions already posed, comments on the solutions discussed in the journal, etc. to Resonance Indian Academy of Sciences, Bangalore 560 080, with "Think It Over" written on the cover or card to help us sort the correspondence. Due to limitations of space, it may not be possible to use all the material received. However, the coordinators of this section (currently A Sitaram and R Nityananda) will try and select items which best illustrate various ideas and concepts, for inclusion in this section.

From B Bagchi, Indian Statistical Institute, Bangalore.

1 Customers in Book Exhibition

The reader is warned that though the problem looks very simple, the solution may not be easy! However, the reader is encouraged to try this problem seriously.

There was a big crowd of customers in a book exhibition. It turned out that for any two of the books on display, there was a unique customer who wanted these two books (and possibly more). However, no customer wanted all the books. Can you decide if there were more books or more customers?

From V Rajaraman, Indian Institute of Science

2 Self-Copying Program

Can you write a program in C which prints its own source code? How about writing such a program in other languages like Fortran?



3 The Population Explosion

R Nityananda, Raman Research
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We have received reactions from readers which suggest different errors in the reasoning which led to the idea of a population explosion in the past. Summarising, the basic error is in the assumption that all the 2^n ancestors which one person had n generations ago are 2^n distinct people. To see this in an extreme example, it is recorded that the ancient Egyptian royal families would have brother-sister marriages for several generations. In this case, any member would have only two ancestors no matter how many generations one went back. In modern societies, of course, the relationship (of having common ancestors) between a couple who marry is naturally more distant. But even in the case of one's parents being first cousins (not rare in some parts of our country) the number of great grandparents is reduced from eight to six. The real surprise is that this effect *must* operate. Even in cases where one thinks that two of one's ancestors were unrelated, if one goes back far enough they in turn have common ancestors, so one is always overcounting!

*Discussion of questions
raised in **Resonance**
Vol.1, No.1.*

The basic error is in the assumption that all the 2^n ancestors which one person had n generations ago are 2^n distinct people.

4 A Question of Weight

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The question regarding the measured weight of a box containing a bird provoked readers into different responses. When the bird sits in equilibrium at the bottom of the box, we would all agree that its weight is registered. The bottom of the box clearly exerts an upward force on the bird, counteracting its weight. Correspondingly, the feet of the bird push down by an equal amount (Newton's third law). What is interesting is that a similar reasoning applies even when the bird is in level flight. The weight of the bird must be counteracted by an extra pressure difference between the lower and upper surface of its wings (and body). How this difference is generated by the bird flapping its wings is a complicated matter. But we know, since the bird is not falling, that the air must be holding it up. In turn, this extra pressure gets transmitted to the

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bottom of the box and shows up in the measured weight. The same reasoning applies even when the bird is falling with constant (terminal) velocity. Since there is no acceleration, the forces on the bird are balanced.

We leave it to our readers to now convince themselves that when the bird is falling with an acceleration g (i.e. neglecting air resistance) its weight is *not* registered. During the period when it is coming to rest after striking the bottom of the box, the bird is decelerating. The balance shows *more than* the weight of box plus bird (which is one reason why one should not jump on weighing machines).



Clash of the titans ... The first encounter between the two eminent theoretical physicists, Wolfgang Pauli, then a young man, and Paul Ehrenfest, who was already reputed, is an amusing story. Ehrenfest is supposed to have told Pauli: "I like your papers better than you". Pauli's answer: "That is strange, because I like you better than your papers".



Optical illusion ...



The Origins of Science

Part I: Thales' Leap

Gangan Prathap

Science is arguably the most revolutionary social activity known to us. It has transformed us and our environment in ways unimaginable three thousand years ago. If we are healthier, wealthier and wiser (but maybe not happier?) than our forefathers, it is largely due to modern science. Unfortunately, not many of us stop to reflect on how this unique social activity originated. In this essay in two parts, I hope to offer an account that is representative rather than comprehensive or definitive. It reflects and is limited by my own reading on this subject but I hope that it may persuade the reader to enquire further into the nature of the origins of science. Part I deals with the period leading to the great intellectual leap made by the Ionian philosopher Thales. Part II, which will appear in a future issue will complete the study of the Greek odyssey into philosophy immediately after Thales.



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Roots of Science on Greek Soil

The most beautiful account of the origins of science that I have read so far is presented by H D F Kitto in his classic study of Greek civilization titled *The Greeks*. I therefore unashamedly draw copiously from it for this essay on the origins of science, for science took root, only once in history, and that on Greek soil. Kitto advances the argument that the Greeks were the first to show "what the human mind was for." Kitto admits that "the older civilizations of the East were often extremely efficient in practical matters and, sometimes, in their art not inferior to the Greeks, yet they were intellectually barren." The Egyptians, the Chinese and the Indian civilizations are excellent examples of cultures which flowered for thousands of years without recording a major inquiry into the nature or working of the universe in

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terms that could be called a scientific approach. Many of these civilizations were in advanced stages of development; they had invented agriculture and domesticated animals, built vast irrigation works, laid roads, organized themselves into villages, towns, cities and even networked these into empires, administered through systems of laws and government.

For millennia therefore, millions lived rich and varied lives, but died, failing to transmit through the written word, the experience of each generation beyond their own. The Dark Ages, wrote Robert M Pirsig, was merely the resumption of a natural way of life that had been momentarily interrupted by the Greeks.

The Greeks were among the earliest to create and perfect literature in forms other than religious or love poetry. Epic poetry, history and drama, philosophy from metaphysics to economics, mathematics and many of the natural sciences all originated with the Greeks. Here, says Kitto, was a literature which distilled, preserved and enlarged the experience of a people and began nearly three thousand years of modern human civilization. We can now understand why Goethe could make that cruel comment about the poverty of the philosophically illiterate that "he who does not draw from three thousand years is living from hand to mouth."

The modern intellectual tradition is to divide, to specialize and to think in categories or assign to pigeon-holes. The Greek instinct was to do exactly the opposite.

Kitto declares that the most typical feature of the Greek mind is a sense of the fundamental unity in nature and of a wholeness of things - holism describes this frame of mind. We can see this in Homer, says Kitto, where 'particular detail' and 'individual character' are firmly fixed into a 'universal frame'. The modern intellectual tradition is to divide, to specialize and to think in categories or assign to pigeon-holes (we call it reductionism now, or more simply, splitting) whereas the Greek instinct was to do exactly the opposite, to take the widest view and to see things as an organic whole (or lumping). Thus, even today, our scientific traditions can be split down the middle with one half being the lumpers and the other half being the splitters. Lumpers group together as many things as possible; splitters do not hesitate to create new categories whenever they see significant differences.



This Greek instinct for seeing things as a whole was joined by two other fashions, the firm belief in *reason*, and the search for what is *imperishable* in the affairs of men. Before this, all descriptions of the workings of nature were purely speculative, mythological or of the poetic imagination; what was imperishable was that which was transmitted to us by the Gods through the myths. This was true of all civilizations, Greek or otherwise. Kitto describes this well by relating the story of a Chinese philosopher who was asked what the earth rested on. "A tortoise", said the philosopher. "And what does the tortoise rest on?" "A table." "And what does the table rest on?" "An elephant." "And what does the elephant rest on?" "Don't be inquisitive".

From Mythos to Logos

The Greeks were the first to show us that the old Greek myths were only imaginative creations of the inventive mind. They began to glimpse that another level of myths could be discovered through reason and abstraction, which could replace the old myths. Let us now spend some time on this very transcendental leap from 'mythos' to 'logos'. Sociologists and anthropologists will tell us that in every culture the conventional means for structuring any kind of experience is the use of myths. The Greek word *mythos* means *word* - in the sense that it is a decisive or definitive statement on the subject. It can be taken to be the sum total of all early and prehistoric myths of all cultures and civilizations, Greek, Hebrew, Nordic, Vedic, to name a few. It could include superstitions and legends and these have in untold and immeasurable ways informed our present understanding of the world. A myth is always taken as received, from some authority, be it teacher or text and as an authoritative account of the facts or ordering of experience; it is not to be challenged or questioned.

The Greeks were to challenge all this. As opposed to *mythos*, the Greeks offered us *logos*, the Greek word denoting our rational understanding of the world. By rational, we mean that we attempt to arrive at an account of truth that can be demonstrated, discussed and debated using the instrument of reason. However, we

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L Casti, is myth
with discipline.

cannot altogether dispense with myth-making. As the philosopher of science, Sir Karl Popper pointed out, all science is also myth-making, just as religion is, but with an important difference. In science, we deal with myths of a special type, in a special way - scientific myths are testable, change with experience and critical debate. Science, says John L Casti, is myth with discipline. This is the stage known as *positivism*. The value of observation and experiment is now seen and used to challenge myths and not merely accept them because they were received from authority.

The Triumph of Logos Over Mythos

Let us now return to how the Greeks brought about this triumph of *logos* over *mythos*. The Greeks believed that the universe was not built on caprice or chance. They were certain that it obeyed certain laws and that these immortal principles could be discovered and explained. Even in human affairs, as a study of Greek tragedy will show, there is the implicit belief that it is not chance but a universal and inexorable law reigns. There is design, even in what may seem to be the complex but apparently fortuitous chain of events that regularly are the substance of Greek tragedy. The philosopher Whitehead went so far as to say that the Greek tragic poets, rather than the early Greek philosophers, were the true founders of scientific thinking. Thus, we see in the Greek mind, the elements of poetic imagination melding with the elements of reason. As we will see later, these are the first two steps of the full scientific process. There is one more step that was to become part of the scientific tradition only many centuries later - the beginning of the experimental or empirical tradition as an instrument of criticism by which the poetic metaphors could be refined until they gave a more unified and coherent understanding.

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The Greek Philosopher Thales

Going back to the early Greek speculation about the origin and nature of the universe our attention is drawn to a remarkable figure, Thales (625?-546? B.C.) of Miletus in Asia Minor (see

Miletus, Chaldea and Egypt

Miletus was an important port and the richest market in Ionia and traded extensively with many countries in the region. It is not surprising that Thales was a merchant who travelled widely and learned a little of Egyptian mathematics and Chaldean astronomy. Chaldea was a region of ancient Babylonia in what is now south eastern Iraq. The early Chaldean (or Babylonian, as they are often remembered) astronomy between 700 and 500 B.C. was

built up for the very practical business of regulating their calendar and for making predictions; astrology and astronomy, until very recently, were inextricably mixed. They kept detailed astronomical records and could make accurate predictions of the sun and the moon. The Chaldeans also contributed to what could be called *commercial arithmetic*, and the Egyptians developed a sophisticated form of practical geometry (Greek for Land-measuring).

box), the first of the great Ionian thinkers. He is the earliest known Greek philosopher, and was to found what is known as the Ionian school. He is remembered as the first scientist on Aristotle's authority because he is acknowledged as the first who expressed his ideas in concrete but logical, and not mythological, terms. Little that he wrote came down directly to us and what we know of him is through accounts by later Greek historians and philosophers. It is Aristotle who tells us that Thales was the first person to ask searching questions about the underlying material source of all things.

Greek thought so far was confined to grappling with moral, religious and social problems, and their speculative adventures remained restricted to how the universe came into existence rather than how it worked. Thales was to change all this. He was the first Greek philosopher to have predicted the total eclipse of the sun during the year 585 B.C. The Babylonians and Egyptians used mathematics and geometry as tools in practical life. Thales turned these tools into science. Some typical propositions that students are introduced to in their earliest encounters with geometry are believed to have originated with Thales: that a circle is bisected by a diameter, or that the angle inscribed in a semicircle is a right angle. He applied geometrical principles to the problem of measuring the distance of a ship at sea, informa-

Thales is acknowledged as the first who expressed his ideas in concrete but logical, and not mythological, terms.

¹ The usual story of the absent-minded Professor is told of Thales, that on a walk he was so intently looking up into the heavens that he tumbled into a well; but a story of the other kind is related by Aristotle — himself something of a philosopher and therefore not disinterested. Thales was reproved for wasting his time on idle pursuits. Therefore, noticing from certain signs that the next crop of olives would be a large one, he quietly brought an option on all the wine-presses of Lesbos, so that when the large crop came and everyone wanted to make his oil at once, they all had to go to Thales for a press. So he demonstrated that a philosopher can make money enough, if he thinks it worth doing. (From H D F Kitto, *The Greeks*.)

One of the most influential ideas to emerge from Greek thought is that “the universe is not only rational, and therefore knowable, but also simple” (in Kitto’s words)

tion which is vital to trade and commercial interests. He was therefore a very practical man in some ways but in other ways more typical of an absent-minded philosopher. Thales often ‘wasted’ time on idle pursuits.¹

One of these idle tasks that engaged him rather delightfully was the simple question: What is the world made of? *The important leap here is the mere asking of the question.* This was typical of the Ionian Greeks; they had a passion for asking useless questions in a purely disinterested way. Also, they assumed that such questions were capable of being answered. And they knew, as if by a newly developed instinct, that what they were going to find would confirm their faith in a unifying principle that underlies all material forms in nature. Going back to the question Thales asked, he believed, incorrectly as we now know, that this substance was water. Note that Thales preferred to choose something as concrete and tangible as water as his universal substance or immortal principle, and expressed it in terms which were at once ready for objective and critical discussion and for experimental verification. Mythology and theology were giving way to science.

It was a curious answer, but he must have had some reasons for arriving at it. Water is everywhere, on land, surrounding the land, coming down from the clouds, gushing out of springs and wells. It can in turn be solid, liquid, or gas. Thales’ answer was therefore based both on abstract reasoning and the observational evidence gathered through the senses. The most significant implication of Thales’ answer was that in spite of the diversity of appearances, Thales was sure that the world consisted of one single element. This is one of the most influential ideas to emerge from Greek thought: that “the universe is not only rational, and therefore knowable, but also simple” (in Kitto’s words).

There is also some irony in the fact that throughout history, philosophy and metaphysics have oscillated from complexity, multiplicity and pluralism (the world is a manifestation of an



Occam's Razor

William of Occam (also Ockham, Ockam) lived from 1285 to 1349 A.D. He formulated the principle we now know as Occam's razor - *Entia non sunt multiplicanda praeter necessitatem* - "Entities are not to be multiplied beyond necessity", implying that explanations should never be more complicated than they need be. This has come to be regarded as the fundamental organizing principle for all scientific theorizing - although nature

itself may not be simple, the laws describing its working may be constructed from simple principles. More precisely, Occam's razor states that if many explanations are offered, the simplest, that is, the one which makes the fewest assumptions, is often the one that is the most useful and the most likely to be true. Scientific explanations must be simple and useful. This is the very basis for science.

indefinite number of things) to simplicity and monism (the belief that all things are constituted from one single thing, making no distinction even between mind and matter). Thus, as Kitto points out in his book, had Thales met a nineteenth-century chemist and been told that there are sixty-seven elements, he would have objected that this was far too many. Had he come sometime earlier this century and been told by a physicist that these elements were combinations of a fundamental building block, he would have rejoiced and exclaimed, "That's what I've always said".

A few things stand out about this extraordinary leap that Thales made. First, his conjectures and analyses were totally free of any form of religious mysticism. His metaphors were free of mythological symbolism. He was the first person to break away from the usual mythological and supernatural explanations and look for natural causes using a scientific approach. By this, we mean that he tried to combine reason with observation in trying to ask and answer questions about life and the universe. Secondly, we must admire the boldness of his ideas. As Kitto says, "It is as if the human mind for the first time took its toes off the bottom and began to swim, and to swim with astonishing confidence."

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Why is an Ant's Trail Straight?

Problems of Pursuit

Ranganath

This interesting question puzzled the eminent theoretical physicist Richard Feynman when he was young. As a boy he did many ingenious and interesting experiments. One of them concerned ants. One day while taking a bath he placed a lump of sugar at one end of the bath tub and waited for an ant to locate it. Feynman used a colour pencil to mark the trail of his ant. He noticed that the first ant that located the food took a random wiggly path. But the successive ants did not exactly follow the trail. Instead, each ant straightened the trail of its predecessor a little bit. Thus after some time the trail became a near straight line. Many years later Feynman described this process beautifully in the book *Surely you're joking, Mr. Feynman!*. He concluded from his observations that: "It is something like sketching. You draw a lousy line at first, and then you go over it a few times and it makes a straight line after a while." We might argue from this that ants understand geometry. Feynman did not overlook this possibility. He said: "Let me tell you the experiments that I did to try to demonstrate their sense of geometry did not work."

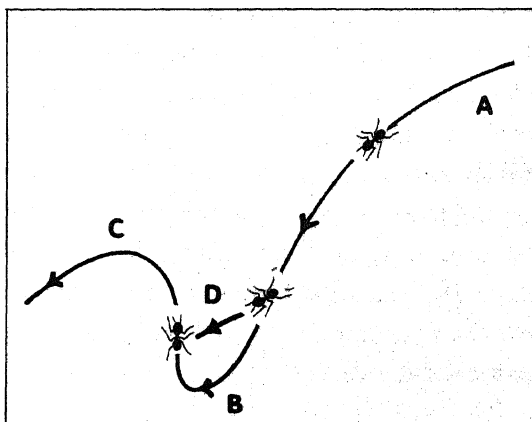
Feynman had recognized the importance of this problem of one ant pursuing another. Historically, pursuit problems are pretty old, dating back even to Leonardo da Vinci. In

recent times this question has become all the more relevant in robotics.

This problem has now been readdressed by Alfred Bruckstein, a computer scientist at Technion, Haifa, Israel. His answer in the case of ant trails will surely be of interest to biologists and others. Incidentally he did this thought provoking work on ants when Haifa was being bombed during the Iraq-Kuwait war.

Since ants have no sense of global geometry, Bruckstein proposed a simple local interaction between them. In this model each of the 'mathematical ants' goes directly towards the one ahead of it. In other words, at any instant of time an ant's velocity vector always points towards the ant immediately ahead. Hence the distance between any two neighbouring ants either remains the same or decreases, of course avoiding collisions. If the leading ant and its immediate follower move in a straight path their distance of separation remains the

Figure 1 The pioneer ant takes the curved path ABC. The immediate follower avoids the bend B and takes the route ADC.



same. However, when the ant ahead is going round a bend the follower heads straight towards it avoiding the bend (see *Figure 1*). This process continues with every successive ant avoiding the kinks in the path of its predecessor. In course of time, the random path continuously shrinks in length and is finally transformed into one of minimum length, which is a straight line.

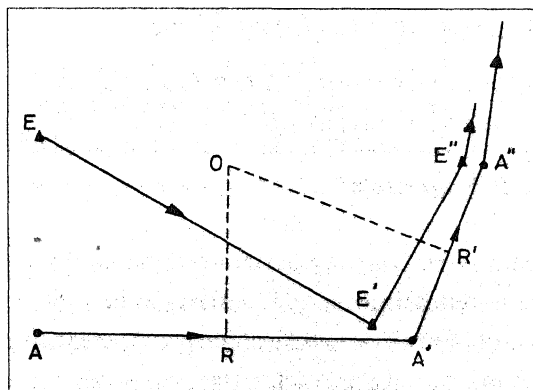
Mathematically this process is governed by a non-linear differential equation. Solving it for the pursuit path of the follower given the trail of the leader is a very difficult task. Although attempts to solve such problems began in the eighteenth century, to date we have solutions only in two cases! The first one concerns pursuit on a straight line at constant speed and the second one relates to pursuit on a circle. Bruckstein has worked out only the limiting behaviour of the solutions of the differential equation. He finds that the solutions finally converge to a straight line. This study has unravelled a possible interaction that can exist in the world of ants. But a word of caution is in order. In principle one can try different trail following models based on other local interactions. These models may also have solutions that finally converge to a straight line. Thus only one of the possible interactions between neighbouring ants has been suggested by Bruckstein.

It is important to mention here that there is one case where the differential equation has a neat solution. Let us say that four ants are located at the vertices of a square, at the centre

of which is a lump of sugar. Can all the four ants reach this lump of sugar simultaneously? Yes, they can. If each ant starts moving at the same speed but follows the ant to its right (or left), then the differential equation yields the answer that all the ants will spiral towards the centre at the same time. Interestingly, in this case each ant covers a distance equal to the edge of the square. This problem has been generalised to the case of different numbers, of ants at arbitrary starting positions with variations of the speed and local pursuit laws.

In this context we recall Littlewood's lovely problem of a lion catching a gladiator. We can recast this problem to our present theme. Let us say an ant A is threatened by an enemy ant E in a closed area. This is not impossible in the world of ants. Further, let us say that the two ants are equally energetic and hence can always move with the same speed. Then surprisingly our ant A can avoid being captured by its enemy E if it adopts the following strategy: The ant A begins by moving at right angles to

Figure 2 The paths taken by ant A and its enemy, ant E, according to the strategy described in the text.



the line of sight AE i.e, the line joining it and the enemy ant (see *Figure 2*). It moves in a straight line along this direction until its path intersects the radial line OR, emanating from the centre O of the closed area, which is parallel to the initial line of sight AE. From here it continues in the same direction AR through a distance equal to it and reaches the new position A'. By this time the enemy ant would have moved to a different position E'. Now A locates the new line of sight A'E' and repeats the whole procedure. By successive applications of this method, the ant A can avoid the enemy ant E eternally. In the process A's own path will be a squiral, i.e, a spiral with successive line segments. More on this problem can be found in Ian Stewart's article in *Scientific American*.

Bruckstein's work not only sheds light on what is going on in the world of ants but is also useful in the world of robotics. We conclude from his work that globally optimal solutions for navigation problems can be obtained as a result of near neighbour co-operation be-

tween simple agents or robots. It is very expensive and technically difficult to make a single robot that can find the shortest path around obstacles. Instead of making a single sophisticated robot we gain considerably by making many simple robots. These can find the best path through a mere pairwise nearest-neighbour interaction.

Next time you seen an ant, approach it in all humility. It is not for nothing that the Bible says

Go to the ant, thou sluggard; consider her ways, and be wise.

(Proverbs 6,6.)

Long live the members of Formicidae.

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Hickory Dickory Dock

Molecular Clues to the Control of Circadian Rhythms

T R Raghunand

Most time keeping systems are based on the sun, reflecting age old patterns of human activity. For most practical purposes, according to our social contract, a day starts when the

sun rises and ends when it sets. But the organisation of activity into day and night cycles is not merely an arbitrary agreement for setting clocks; it is also a biological imperative. (Recall Geetha's experiences in a timeless environment: *Resonance* Vol.1, No.3, 1996.) Most organisms - animals, plants and even microbes, have internal clocks that dictate daily or *circadian* (from the Latin *circa*, about, and *dies*, day) rhythms of a myriad life

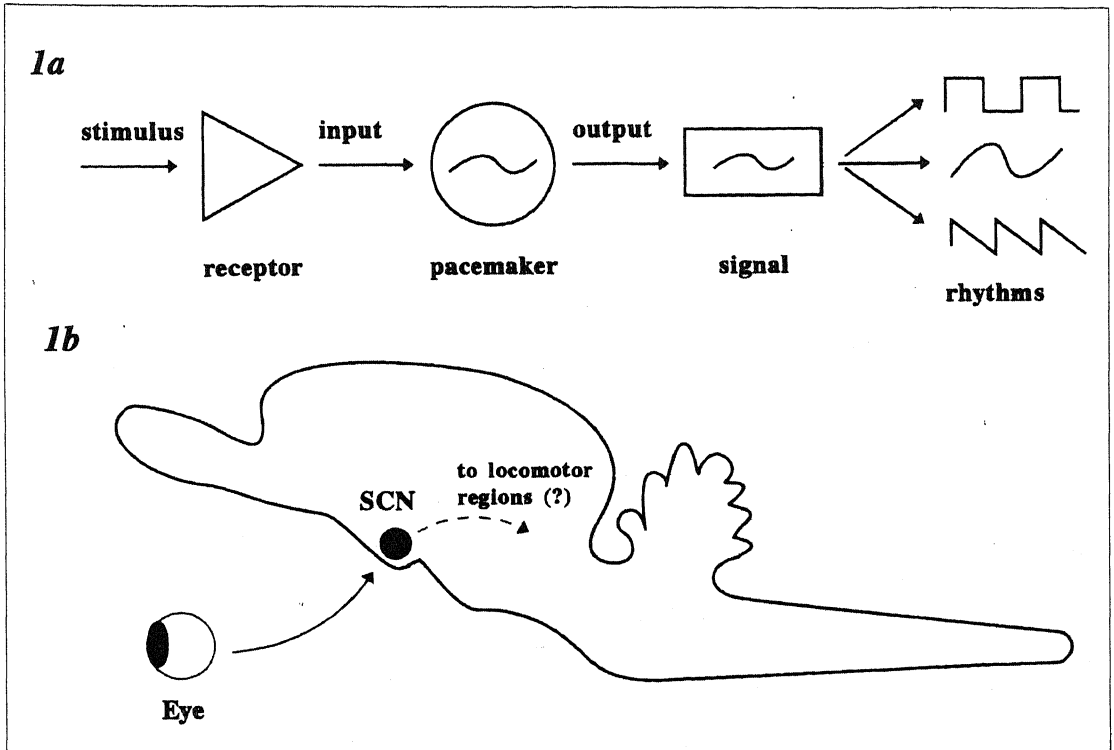


Figure (1a) Schematic representation of the three essential elements of a circadian system. **(1b)** In rats, the pacemaker is the suprachiasmatic nucleus (SCN) present in the brain.

processes like metabolic, cellular and reproductive activity as well as the sleep and wakefulness cycles. The biological clock, like the human artefact, follows the 24 hour cycle of the earth's rotation. Mice are most active at night, while most birds are active during the day. Bees visit the same flower at the same time each day. Photosynthesis in plants is not merely light driven, but follows a circadian rhythm, even when plants are exposed to constant light. Exactly how the internal clock keeps time is a mystery, as is the identity of most of the molecular wheels and gears that make it tick. Although the internal clock itself does not require environmental inputs to

maintain a period of approximately 24 hours, light is an important criterion in synchronising that period with the solar day. All circadian systems therefore require at least three elements. First, a sensory pathway to receive cues from the environment. Second, a pacemaker or clock, that lies at the heart of the system, to generate the rhythm. Finally, an output pathway through which the pacemaker regulates the rhythms of organismal activity (*Figure 1a*)

As a general feature it appears that pacemakers help to anticipate the needs of the organisms through the cyclic regulation of specific

Early studies have indicated that the underlying mechanisms of circadian rhythms involve intracellular and biochemical processes.

target genes. Early studies have indicated that the underlying mechanisms of circadian rhythms involve intracellular and biochemical processes. Today it is clear that the activity of several genes in various organisms oscillates following a circadian cycle. One question concerns whether they oscillate as a consequence of a general circadian rhythm or whether they are responsible for it, and are therefore a part of the molecular architecture of the endogenous clock. The paramount questions are — how does the clock itself run, how is it reset, and how does the output regulate cellular activity?

In all organisms studied so far, there is a pathway that is sensitive to light. But the receivers of this cue are varied due to the anatomical diversity of systems. In most animals light hits the eyes, and the information is then transmitted to the appropriate region of the brain containing the circadian pacemaker. In single-celled organisms, light acts directly on photosensitive compounds, which in turn activate other cellular pathways. In many higher organisms a special pine-cone shaped structure called the pineal gland, is found very close to the surface of the head

where it is exposed to light. It not only receives information about light but is also known to set the pace for circadian rhythms in certain fish, reptiles and birds.

In mammals, the pineal gland is buried deep within the centre of the brain and has lost its ability to be light sensitive. Its role in circadian rhythms has been superseded by a cluster of nerve cells located at the base of the brain called the suprachiasmatic nucleus (SCN). The SCN has been identified as the pacemaker for mammals where rhythms are both set and maintained. In rats, the SCN is believed to send a signal to the locomotor regions of the brain, where it determines periods of physical activity and inactivity (*Figure 1b*). Recent studies have shown that individual cells of the pineal gland of some birds and the SCN of mammals can maintain their rhythmic oscillations even when removed from the animal. One conclusion drawn from this is that each oscillating cell contains all the components necessary to maintain the rhythm, requiring no input from adjacent cells. Technically the oscillations are said to be 'cell autonomous'.

The Molecular Basis of Rhythms — Clues from the Fly

Molecular genetics is a powerful tool that has been used to identify key elements in the generation and maintenance of rhythms. In

The SCN has been identified as the pacemaker for mammals

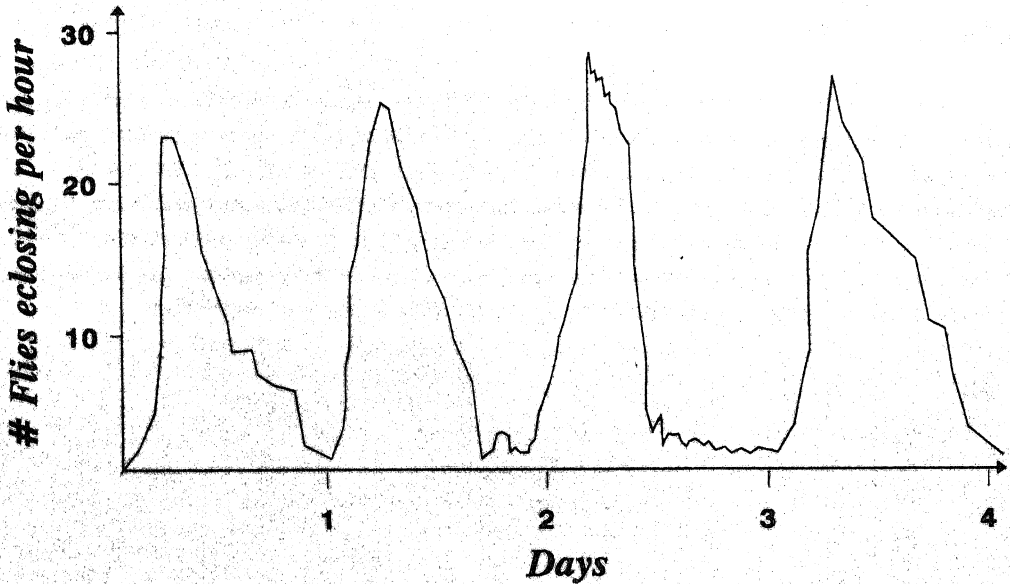
(*per* and *tim* refer to the genes; *PER* and *TIM* refer to the proteins.)

Rhythms in *Drosophila*

Rhythms in *Drosophila* are primarily analysed by examining patterns of eclosion (emergence of adult flies from pupae) and locomotor activity.

The eclosion profile which shows a 24 hour period in wild type flies is depicted below graphi-

cally. (Data taken from Konopka and Benzer's Clock mutants of *Drosophila melanogaster*. *Proc. Natl. Acad. Sci. USA*, 68: 2112-2116 (1971).) In mutants (e.g *per*, *tim*) flies, this rhythm is altered (arrhythmic, short period or long period) (not shown).



the early 70's Ronald Konopka, a student of Seymour Benzer, in a pioneering genetic approach, identified a gene that controlled rhythm in the fruit fly *Drosophila melanogaster*. He named the gene *per* for period, since mutations in this gene upset the 24 hour cycle of the fly. For over 10 years since the gene was isolated, molecular biologists have been looking at its expression with the hope of understanding how a single gene controls circadian rhythms. Researchers studying the first step leading to PER protein synthesis, the produc-

tion of messenger RNA (mRNA) by the gene, found that *per* activity cycled with a 24 hour period. Cycling seemed to be controlled in part by the PER protein itself, a phenomenon called *autoregulation*. As the levels of *per* mRNA increased, cells produced more PER protein, which then went into the nucleus and shut off its own gene. That caused the mRNA and protein levels to drop and eventually released the gene from its self imposed repression, allowing it to be active again. But this by itself couldn't constitute a clock since a pro-

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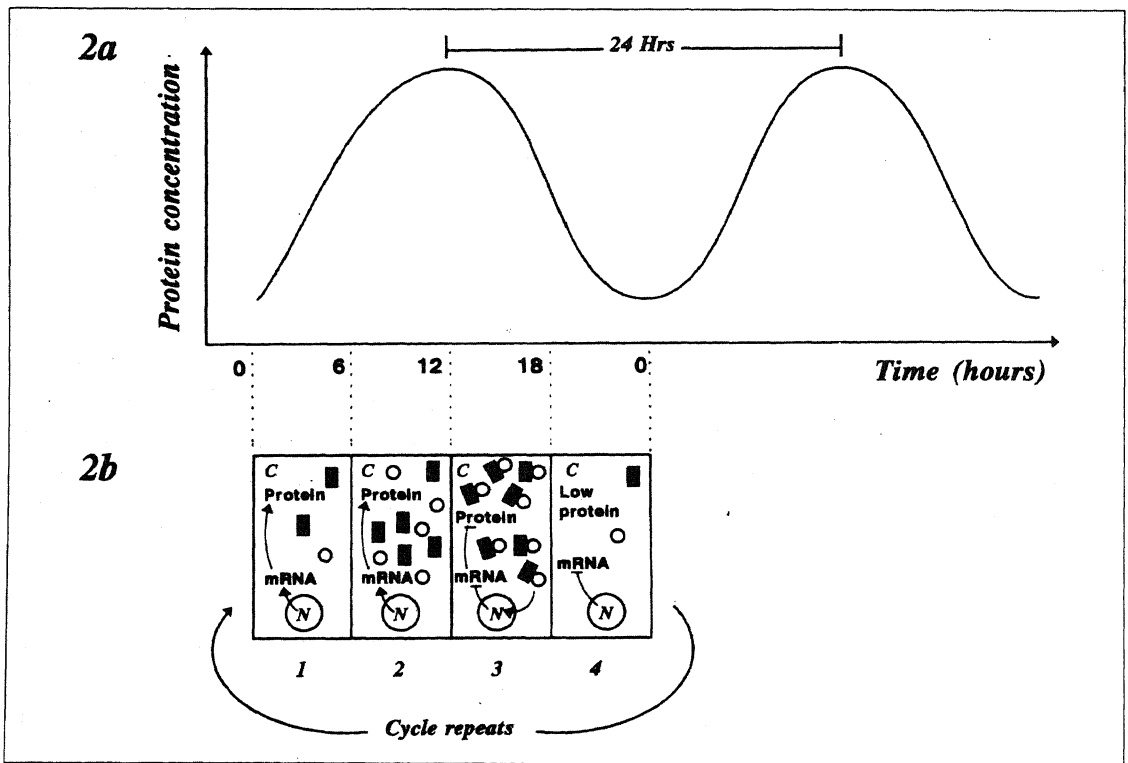
tively constant level rather than end up cycling in an endless rhythmic fashion. A second player had to be involved to complete the puzzle.

Towards Completion of the Jigsaw

Yet another vital component of the clock was discovered in November 1995, marking one of the most exciting finds in clock research. Two groups of workers independently cloned a

tein with an autoregulatory loop would damp out concentration swings, reaching some rela-

Figure 2 Proposed model for creating a rhythm or oscillation based on recent experimental results in the fruit fly. (a) A graphical representation of cyclic variation in protein concentration against time. (b) The probable molecular events. N-nucleus, C-cytoplasm, PER protein, ■ TIM protein ○. The concentration of proteins builds up (1 & 2); the two associate at a critical concentration and the dimers enter the nucleus to shut off their own synthesis (autoregulation), resulting in the decline of PER and TIM in the cytoplasm (phase 3); decreased levels of the proteins in the cytoplasm (phase 4). Absence of the PER-TIM dimer allows repression to be lifted, leading to the next oscillation.



Two groups of workers independently cloned a gene called *timeless (tim)* and showed that the protein made by this gene interacts with the PER protein

gene called *timeless (tim)* and showed that the protein made by this gene interacts with the PER protein (*Science* 270:732-733, 1995). Sure enough its mRNA levels cycled up and down every 24 hours just like the *per* mRNA ! In addition, mutations in *per* upset *tim* mRNA cycling and vice versa, suggesting that under normal circumstances TIM and PER somehow work together to turn down both of their genes. To regulate the genes, PER apparently should first accumulate in the cytoplasm until something triggers its move to the nucleus. Moreover accumulation of PER and its subsequent migration into the nucleus of the cell seemed to be blocked in mutants lacking a functional TIM protein. All these findings led to the proposal that the binding of the two proteins to each other played a role in the timing of PER nuclear entry, and thus the circadian cycle itself. According to the model (Figure 2), the PER protein is relatively unstable when first made in the cytoplasm. As a

As more clock components and more mechanisms become defined, and the field of circadian rhythms continues its demystification process, we may perhaps very soon be able to answer the eternal question: "What makes us tick?"

result, the protein molecules accumulate slowly till they run into TIM proteins, being made at the same time. The proteins then bind one another, forming stable dimers that enter the nucleus. There they shut down the expression of their own genes in association with yet unidentified nuclear partners, and may affect other genes as well. The identification of these genes would be the next logical step in the quest to delineate the pathway by which rhythms are manifested.

In addition to the fly, clock genes have been identified in a host of organisms such as the bread mould *Neurospora (frequency)*, mouse (*clock*), and hamsters (*tau*), ushering in a revolution in clock research. As more clock components and more mechanisms become defined, and the field of circadian rhythms continues its demystification process, we may perhaps very soon be able to answer the eternal question: "What makes us tick?"

Suggested Reading

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Michael Rosbash. Molecular control of circadian rhythms. *Curr.Opin.in Genetics & Dev.* 5: 662-668. 1995.

M P Myers et al, A Sehgal et al, N Gekakis et al, *Science* 270 : 805-808, 808-810, 811-815. 1995.

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Environmental Chemists Share the 1995 Chemistry Nobel Prize

An Honour for Unearthing the Secrets of our Ozone Roof

S Parthiban

"The whole of my remaining realizable estate shall be dealt with in the following way: the capital, invested in safe securities by my executors, shall constitute a fund, the interest on which shall be annually distributed in the form of prizes to those who, during the preceding year, shall have conferred the greatest benefit on mankind."

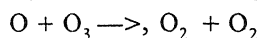
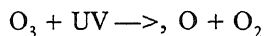
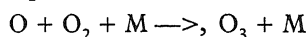
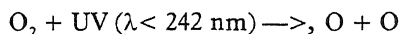
— *from the will of Alfred Nobel.*

The 1995 Nobel prize for chemistry to the trio — Paul Crutzen, Mario Molina and Sherwood Rowland — is the first chemistry Nobel for any environmentally related work. While the announcement came as a surprise to many, the Nobel committee had clearly adhered to the will of Alfred Nobel. By detailing the delicate balance that maintains the ozone layer and showing how human activity on the earth is perturbing it, "the three researchers contributed to our salvation from a global environmental problem that could have catastrophic consequences," reads the citation from the Royal Swedish Academy of Sciences.

Leaky Roof over the Living Room

Ozone (O_3), a molecule composed of three oxygen atoms, is found primarily in the strato-

sphere between 12 and 50 km above the Earth's surface. The formation of ozone from molecules of oxygen in the upper atmosphere is part of a cyclic series of chemical reactions that prevents the sun's ultraviolet (UV) radiation from reaching the earth. The steps are illustrated in the following mechanism, proposed by Chapman in 1930.



where M represents another molecule of oxygen or nitrogen that is unchanged in the reaction.

Why worry about the ozone layer? Without it human beings would suffer serious biological effects from solar radiation, including a large increase in the incidence of skin cancer and irritating eye disorders. Light-skinned people, especially children, are most at risk. Closer to the earth, however, ozone is a harmful pollutant that causes damage to lung tissue and plants.

Why worry about the ozone layer? Without it, human beings would suffer serious biological effects from solar radiation, including a large increase in the incidence of skin cancer and irritating eye disorders.

1995 Nobel Laureates in Chemistry



Paul J. Crutzen (1933-)



Mario J. Molina (1943-)



F. S. Rowland (1927-)

"the three researchers contributed to our salvation from a global environmental problem that could have catastrophic consequences."

After years of observation and experimentation, it seems clear that the ozone layer is affected by natural and man-made activities. Scientific measurements have documented a downward trend in the total column amount of ozone over mid-latitudes, as well as substantial ozone loss over polar regions during the spring seasons.

Theories to Explain the Ozone Thinning

Theoreticians came up with three competing models to explain the ozone depletion. One group of scientists blamed the 11-year solar cycle—the periodic waxing and waning of the sun's energy output. A second group suggested that natural changes in stratospheric winds were responsible. But a third theory held man-made chemicals as the culprits. The fast paced research of the last two decades proved that ozone in the stratosphere is removed predominantly by catalytic cycles involving gas phase reactions of active free radical species in the HO_x , NO_x , ClO_x , and BrO_x families.

Crutzen was instrumental in establishing the nitrogen oxide chemistry in 1970. The following year, Johnston made the connection between supersonic transport emissions and the ozone layer. Until then, it had been thought that the radicals H , OH and HO_2 (collectively called HO_x) were the principal catalysts for ozone loss. The next leap towards a better understanding of ozone chemistry was in 1974, when Rowland and Molina first suggested that chlorine from chlorofluorocarbons (CFCs) was destroying the ozone layer. At that time, several papers had been published indicating that CFCs were excellent tracers in the troposphere.

CFCs set the Chlorine Atoms Free

CFCs is the name traditionally given to the group of fully halogenated methanes. They were invented in 1928 as safe alternatives to ammonia and sulphur dioxide refrigerants. Rowland and Molina recognized that once CFCs are released into the troposphere, they will remain there until transported to the

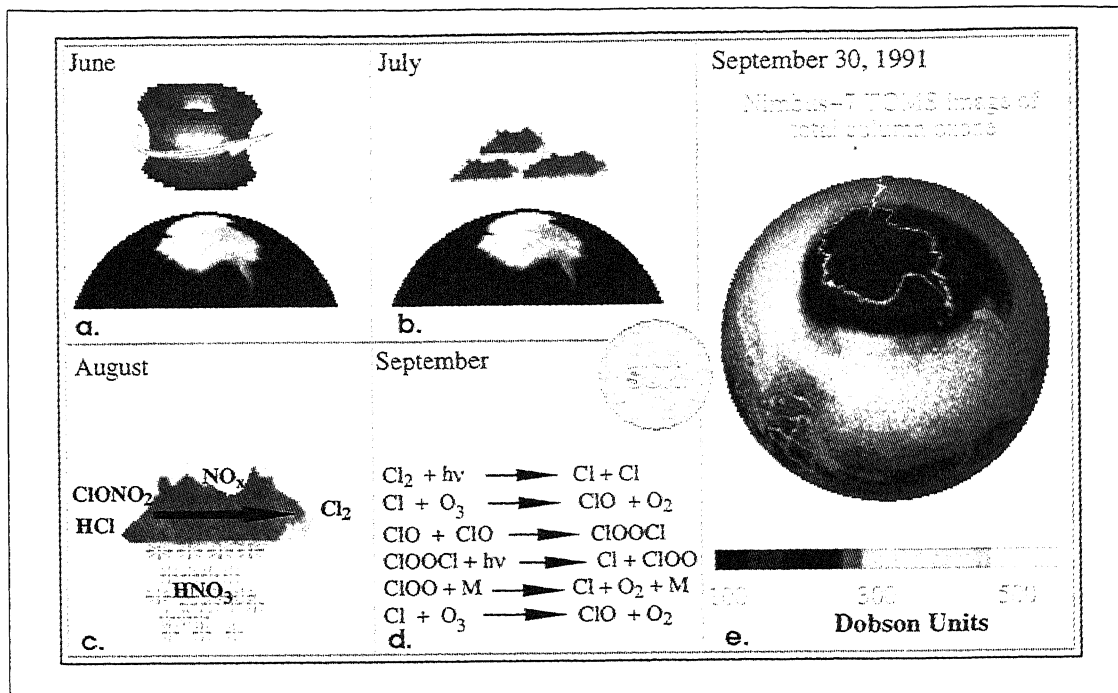
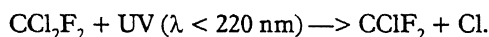
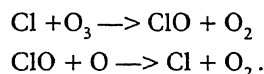


Figure 1 The sequence involved in the formation of the ozone hole. a) Polar vortex circles Antarctica in winter. b) Temperatures drop low enough to form clouds known as polar stratospheric clouds (PSCs). c) PSCs denitrify and dehydrate the stratosphere through precipitation and convert HCl and ClONO_2 into more reactive chlorine. d) The arrival of the sun photolyses the Cl_2 to radicals that can catalyse ozone destruction. e) The ozone hole is completely established in September and October (1 Dobson Unit = 2.69×10^{16} molecules of ozone cm^{-2}). The polar vortex breaks down in November and the ozone level attains normal values in December (not shown in the figure).

stratosphere and decomposed by solar UV radiation.

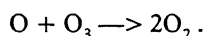


The atomic chlorine released reacts with ozone as follows:



The chlorine atom thus freed, can participate once again in the breakup of ozone molecules.

The net effect of this pair of reactions is the conversion of atomic oxygen (O) and ozone into molecular oxygen (O_2).



The quantitative aspects of the ozone hole, however, could not be explained by this cycle. As a result, several other proposals have been made for the catalytic mechanism linking halogen radicals to the chemical destruction of ozone. The catalytic cycle that is considered

Milestones in Ozone Research

1839 - Schonbein discovered ozone using a chemical test with potassium iodide paper.

1880 - Hartley recognized that the 293nm cutoff in the solar UV radiation at the Earth's surface corresponds very closely with the UV absorption spectrum of O₃.

1926 - Dobson developed an ultraviolet spectrophotometer to measure the total column ozone.

1930 - First qualitative photochemical theory for the formation and decomposition of ozone in the atmosphere was formulated by Sidney Chapman.

1950 - Bates and Nicolet drew attention to the role played by H, OH and HO₂ (products of photolysis of water vapour) in the catalytic reduction of odd oxygen above 60km.

1970 - Paul Crutzen suggested that additional important processes must be taken into account in order to correctly describe the photochemistry of the atmospheric ozone.

1971 - Johnston made a connection to supersonic

transport emissions. This resulted in a very intensive debate among researchers as well as among technologists and decision makers.

1974 - Rowland and Molina established the possibility of major stratospheric ozone depletion from CFCs.

1978 - Nimbus-7 satellite was launched. It contains the 'Total Ozone' Mapping Spectrometer that measured the daily ozone concentration globally till 1993.

1985 - The British Antarctic Survey announced their startling discovery of an 'ozone hole' over Halley Bay, Antarctica.

1987 - Molina and his wife Louisa proposed a chlorine chain involving ClO dimer formation which is now thought to account for the massive ozone destruction.

1995 - Crutzen, Molina and Rowland were jointly awarded the Nobel Prize in Chemistry for their pioneering work on the subject of formation and decomposition of ozone.

currently involves the formation of ClO dimer at low temperatures followed by photolysis or thermal decomposition (*Figure 1d*) proposed by Molina and his wife Louisa.

A Hole has Opened in the Southern Sky

Anxiety deepened when a continent-sized hole (as wide as the United States of America and as deep as Mount Everest) which had eroded the ozone from 40 km above the Earth and eventually extended downwards to 15-20 km in the

ozone layer was detected in the 1980s over Antarctica by a British team. Unravelling the reasons for this massive destruction of ozone has involved a vast collaborative effort, in which the three laureates have remained active. The series of processes currently seen as responsible for the ozone hole formation are presented in *Figure 1*. Some of them occur simultaneously in parallel stages.

The Antarctic ozone hole, once a mystery, is now one of the best understood aspects of the

entire subject thanks to the pioneering research by Crutzen, Molina, Rowland and several others. It is now accepted that chlorine chemistry is responsible for the ozone depletion. Yet chlorine photochemistry alone cannot explain the entire ozone loss; chemists believe that Antarctica's unusual meteorology is also responsible for setting up conditions that allow photochemical ozone destruction.

Early Sign of Coming Doom

Although a fairly solid picture has emerged about the global ozone loss, many pieces of the ozone puzzle are still missing. Will new ozone problems develop in the near future? Despite the complexities and uncertainties, almost everyone agrees on the following: Chemistry is central to understanding any phenomenon associated with ozone layer depletion.

Under the auspices of the United Nations, the major industrial countries have agreed to cease production of CFCs. The United Nations Environment Programme and the Ozone Secretariat invited the world community to observe 16 September, 1995 as the first-ever International Day for the preservation of the ozone layer. This day was designated to commemorate the signing, in 1987, of the Montreal Protocol on substances that deplete the ozone layer.

At last, the world is waking up to protect the ozone shield for future generations! Scientists are now involved in developing safe substitutes for CFCs. It is only fitting that the 1995 Nobel prize in chemistry has been awarded to the researchers who played a key role in identifying the chemicals and mechanisms by which the ozone destruction occurs.

*Men and women carry on:
making more of self is fun.
But before all world is gone
something drastic must be done.
Is there still a little chance
of putting end to doomsday dance?*
(-L.O. Bjorn)

Suggested Reading

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The Making of a Scientist

A Life Worthy of Admiration and Imitation

Raghavendra Gadagkar



Naturalist

E O Wilson

Island Press/Shearwater Books

Washington DC, USA. 1994

pp xiv+380, \$24.95



E O Wilson

it's the same Wilson in all the above and more avatars.

Edward Osborne Wilson, Pellegrino University Professor and Curator in Entomology at the Museum of Comparative Zoology, Harvard University, is probably known to different people for different things. Some know him for creating the science of sociobiology and for being in the eye of the storm raised by the human sociobiology controversy. Some know him as the social insect specialist, author of *Insect Societies* and, the Pulitzer prize winning, *The Ants* written with Bert Hölldobler. Others know him for his theory of Island Biogeography, developed along with the legendary ecologist, Robert H MacArthur. Still others know him as the most influential spokesman for the study and conservation of biodiversity and author of *The Diversity of Life*. I do hope that many Indian students by now know him as the author of the quotation "The worst thing that can happen, *will* happen, is not energy depletion, economic collapse, limited nuclear war, or conquest by a totalitarian government..." reproduced on page 23 of *Resonance*, Vol.1, No.3, 1996! Surprising but true,

Coming from the horse's mouth, this memoir of his life and times and of his evolution as a scientist is a uniquely enjoyable read. Books like this one should be made compulsory reading, instead of, not in addition to, one of the books on biology that students are now required to read. Students would learn a lot more and would, for once, enjoy the process of learning. Wilson describes himself as a happy man in a terrible century. But why terrible century? Because Wilson laments: "In one lifetime exploding human populations have reduced wilderness to threatened nature reserves. Ecosystems and species are vanishing at the fastest rate in 65 million years". But to go back to the beginning, Wilson begins by recollecting how at the age of seven he stood "in the shallows of Paradise beach, staring down at a huge jellyfish in water so still and clear that every detail is revealed as though it were trapped in glass....I want to know more but I am afraid to wade in deeper and look more closely into the heart of the creature.....The jellyfish, I now know was a sea

nettle, formal scientific name *Chrysaora quinquecirrha*, a scyphozoan, a medusa, a member of the pelagic fauna that drifted in from the Gulf of Mexico and paused in the place where I found it.... There was trouble at home in this season of fantasy. My parents were ending their marriage that year. Existence was difficult for them, but not for me.... Each morning after breakfast I left the small shorefront house to wander alone in search of treasures along the sand”.

The fact that a fishing accident in which the spine of a fish pierced the pupil of his right eye, and left him with full sight in the left eye only, did not deter Wilson from pursuing natural history: “The attention of my surviving eye turned to the ground. I would thereafter celebrate the little things of the world, the animals that can be picked up between thumb and forefinger and brought close for inspection.” Wilson’s prescription for the making of a naturalist should come as an eye opener for today’s parents and teachers: “Hands-on experience at the critical time, not systematic knowledge, is what counts in the making of a naturalist. Better to be an untutored savage for a while, not to know the names or anatomical details. Better to spend long stretches of time just searching and dreaming”.

Wilson spent most of his childhood and a great deal of his adulthood catching butterflies, digging up ant nests and aiming pebbles at the heads of snakes so as to stun and seize them under water. I am sure many of us recall similar phases in our lives. What then is the



difference? Why did we all not go on to become naturalists of his class? Wilson anticipates this question from his readers and provides a convincing answer - “Most children have a bug period. I never grew out of mine”, he admits. Wilson’s frankness makes the book truly enjoyable. He describes J D Watson, the co-discoverer of the structure of DNA, as “the most unpleasant human being I had ever met. He came to Harvard as an assistant professor.....with a conviction that biology must be transformed into a science directed at molecules.....and re-written in the language of physics and chemistry.....What had gone before, ‘traditional biology’ — *my* biology — was infested by stamp collectors who lacked the wit to transform their subject into a modern science...At department meetings....[he] radiated contempt in all directions”. When Watson became the Director of the Cold Spring

Harbor Laboratory, Wilson admits commenting to his friends that "I wouldn't put him in charge of a lemonade stand" but graciously goes on to confess: "He proved me wrong. In ten years he raised that noted institution to even greater heights by inspiration, fund raising skills and the ability to attract the most gifted researchers." I hope this is bait enough for my molecular biology colleagues and the already converted molecular biology students to read the book.

But I wouldn't blame Watson after all. These encounters appear to have made Wilson obsessed with the idea of raising organismic biology to a respectable level without necessarily succumbing to the molecular pressures. It is now a matter of history that Wilson has been at the forefront of this very successful enterprise. I cannot do better than follow Wilson and quote Stuart Mill who said that "Both teachers and learners fall asleep at their posts when there is no enemy on the field." Indeed Wilson became so preoccupied with creating syntheses of various branches of organismic biology that, in the only excessively modest passage in the book, Wilson says, "Knowing where my capabilities lay, I chose the second of the two routes to success in science: breakthroughs for the extremely bright, syntheses for the driven." In the rest of the book Wilson has perfected the art of being un-modest without a trace of immodesty, of being frank and objective about one's own achievements, like a true scientist. One of my favourites is his description of the massive book *The Ants* that he wrote with Bert

Hölldobler: "It contained 732 double-columned pages, hundreds of textbook figures and color plates, and a bibliography of 3,000 entries. It weighed 7.5 pounds, fulfilling my criterion of a magnum opus - *a book which when dropped from a three storey building is big enough to kill a man*" (italics, mine).

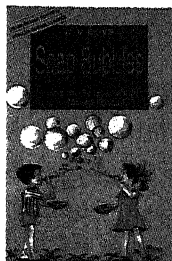
Autobiographies are not easy to review. A reviewer can at best hope to whet the appetite of the reader by giving him tantalizingly brief glimpses into the life of the man and the nature of the memoir. That is what I have attempted to do. I cannot find stronger words to recommend this unique combination of autobiography, history, biology and philosophy. Reading *Naturalist* is the most pleasurable way to learn, reflect and shape one's career in science. When I read it, my only complaint was the book came to an end! How many readers of *Resonance* would succeed in laying their hands on the book is a difficult question to answer but I strongly suspect that a relatively inexpensive paperback would hit the stands soon. In any case I believe that knowing about a good book that is not easily available is better than being ignorant of its existence. I have often heard good things about a book and have had to let the desire to read it grow with me — the longer I have had to wait, the more I have enjoyed finally reading it.

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Games with Bubbles

An Invitation to a Wonder Land of Physics

G S Ranganath



*Soap Bubbles -
And the Forces which Mould Them*

C V Boys

Vigyan Prasara Reprints: Popular
Science Classics,
Department of Science and
Technology, New Delhi, 1995.
pp 109. Rs 30.

It is probably very difficult to find a person who has not been charmed by the exquisite beauty of soap bubbles. Invariably, our appreciation of soap bubbles ends with an admiration of their shapes and colours. We do not realise that there is a profound science behind their beauty. The best book to start learning the physics of soap bubbles is the monograph of Boys. His book which evolved out of three demonstration lectures has justifiably become a classic. The rich variety of experiments that are described without the aid of a single equation is really astounding. Natural phenomena and their relation to surface tension are discussed, a rare quality in present day text books. This book is a must in every science lover's book shelf.

Though the book is supposed to be on soap bubbles, Boys begins with a discussion of liquid drops. He appreciated the fact that a study of drops which is easy to undertake, naturally leads to the physics of bubbles as

This book which evolved out of three demonstration lectures has justifiably become a classic. The rich variety of experiments that are described without the aid of a single equation is really astounding.

well. Boys was probably aware that precise hints would be necessary for anyone else, to repeat, let alone improve upon, his demonstrations. In view of this, he has given useful tips towards the end of the book. The lectures can even be looked upon as a primer on the classical physics of his time. Through a description of simple, elegant and beautiful experiments Boys builds the theory of surface tension and reveals its end effects. These experimental results are relevant even 106 years later. It is not out of place to recall a few of them here.

The discussion on the effects of local variations in surface tension resulting from concentration or thermal gradients is very instructive. We have all read of the erratum of camphor on water. Boys argues that the same physics is behind the continuous melting of a candle or formation of wine droplets on the walls of a vessel containing wine. His demonstrations on the instabilities of the shapes of drops are very impressive, in particular the one on the shape transformation in a rotating liquid drop. At low rotation it is flattened at the poles. At higher rotation it breaks into a liquid ring surrounding the drop. At much higher rotations the

C V Boys

C V Boys had varied tastes in science. He became internationally famous for his work on the measurement of the gravitational constant G . It may be pointed out that his early education was in mining and metallurgy and one of his early scientific papers, published in *Nature*, was on learning capabilities in garden spiders. Interestingly, he also wrote a book on weeds. He was one of the few scientists to successfully popularise science. Towards the tail end of 1889 he gave three lectures on soap bubbles to a juvenile audience. These lectures, delivered at the London



Institute, were later enlarged into a book which saw many editions. Strangely, all these editions were published by 'The Society For Promoting Christian Knowledge' under the series 'The Romance of Science'. Boys lived to see the French, German and Polish translations of his book. Incidentally, he also developed a toy named 'Rainbow Cup' which was patented and released to the market. Here a flat soap film is spun at a high rate leading to a thinning at the centre which results in a ring of colours as in a rainbow. This was a popular toy for quite some time.

breaks into droplets orbiting the central flat drop. The experiments pertaining to cylindrical drops are simply beautiful. Their instabilities in a variety of situations have been described in simple terms. He gives elegant answers to such questions as: Why do we find fine beady strands in the web of a spider? Why does water running down a tap or emanating as a jet, break into droplets? In this context one of his demonstrations must have left a lasting impression on his audience. Boys showed that even the inaudible ticks of a watch can be made to echo aloud in a big hall by coupling it acoustically to a jet of water falling on a stretched rubber sheet. The growing instabilities act as an amplifier.

His adventures with bubbles are equally fascinating. Formation of bubbles inside bubbles, study of diffusion of gases through

soap bubbles, effects of buoyancy on a bubble inside a bubble are some of the extraordinary phenomena discussed by Boys. There is also an interesting section on the production of curved soap films with 'zero' curvature and attractive soap film configurations inside wire frames of different geometries. Experiments pertaining to the mechanical strength of cylindrical bubbles are equally intellectually engrossing. Boys also considered in his book, the effects of electric fields on drops and bubbles. With electrically charged bubbles he demonstrates analogues of the Faraday cage and electrostatic interaction between charged bodies. His experiments on the effects of an electric field on the structure of jets are worth repeating even today.

The digression into curves in general and conic sections in particular is a pleasant inter-

Bashing the British System of Units

"I have felt constrained to use the archaic British units of measurement, as the unfamiliar metric terminology would have distracted the attention of the majority for whom this book is intended, who have spent untold hours that might have gone into mathematical or general education in performing ridiculous operations such as reduction, compound multiplication and practice which our British methods of measurement necessitate, but which in more enlightened countries are wholly unnecessary."

C V Boys, in his preface to the new and enlarged edition of the book 'Soap Bubbles'.

lude. His expositions on curves generated by the focus of a conic section as it rolls on a straight line are very illuminating. One effortlessly learns a lot of geometry relevant to the shapes of the bubbles.

Now about the Indian edition of this marvelous book. I could not lay my hands on the first edition of this monograph. However, I have

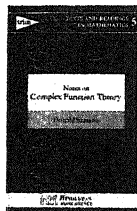
gone through the 1920 edition and find that the Indian edition agrees with it in many respects. The Department of Science and Technology which financed this venture should be congratulated on undertaking such an activity. Also its decision to publish at a low price is truly commendable. Unfortunately, the Indian edition is not a good representative of the original monograph in some respects. The editors could have handled this task with a little more care. They provide their own 'explanatory notes' towards the end of the book. Some of these notes are even misleading. For example it has been stated that a gold-leaf electroscope detects radiation while in fact it can only detect ionizing radiations. The text needs the geometrical dimensions of shillings, etc, and not their monetary relationship with the British Pound. Further, Figure 17 is not consistent with the text pertaining to the instability of a rotating liquid drop.

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Complex Function Theory

A Concise and Interesting Book!

Gadadhar Misra



Notes on Complex Function Theory

Donald Sarason

TRIM #5, Hindustan Book Agency,

New Delhi 110 017. 1994.

pp 184. Rs 180.

Over the last few years, there has been a substantial increase in the number of text books on complex analysis. Most of these texts have common core material. There is no serious disagreement at present about the logical order in which this material must be presented. Besides, elegant and economical proofs have been found for most of the important results. This makes the task of writing a new book on complex analysis at an elementary

Within the limitations of space the book has an amazing amount of material. The proofs presented are complete and rigorous.

level all the more difficult.

Notes on Complex Function Theory by Donald Sarason is written in a clear style which is concise and interesting. The material is well organised and is presented in a natural sequence.

From the seemingly innocent definition of a holomorphic function, a student often wonders if much of complex analysis is similar to what one has already learnt in real variable theory. She is surprised by the many differences that she encounters between a holomorphic function and a differentiable function of two real variables. The list keeps growing, so much so, that after a while, it becomes impossible to keep track of all these! The book under review has about one hundred and fifty descriptive titles, each of which clearly indicates what is to come in the next page or two. This is certainly very helpful for someone learning the subject for the first time. Here is a sample that is hard to miss even at the first reading :

- (VII.8) Holomorphic functions are differentiable to all orders.
- (VII.13) Holomorphic functions, all of whose derivatives at a point vanish, are identically zero.
- (VII.14) Two holomorphic functions which agree on an open set are identical.

The book begins by clearly explaining the difference between real and complex differentiability. The branch of a logarithm is discussed in detail and is followed by a discussion of analytic continuation. The Riemann surface associated with the function $z^{1/2}$ is constructed. A brief discussion on power series follows. Cauchy's theorem is first proved for a convex region. Cauchy's integral formula is then derived from this. Laurent series and the discussion of poles, singularities, etc. occupy the next chapter. Simply connected domains are introduced via the winding number criterion and then a more general version of Cauchy's theorem is proved. An interesting alternative proof of Cauchy's theorem is provided using Runge's theorem.

The Riemann mapping theorem is presented at the end. (Of course, this is one of the main theorems proved in any serious first course on complex analysis. However, a lengthy discussion on 'normal family' and the lack of motivation for the proof usually combine to discourage a student from learning the proof.) Sarason's book first isolates an extremal property of the Riemann map. The proof is then given in three clear cut steps: 1) existence of a univalent (one-to-one) holomorphic map of the given simply connected domain into the unit disk, 2) existence of a map with the necessary extremal property, 3) proof that the map so obtained is the required Riemann map.

Within the limitations of space (less than two hundred pages) the book has an amazing amount of material. The proofs presented are

There are perhaps a lot of topics that could be added to the book but there is hardly anything that could have been left out!

complete and rigorous. There are perhaps a lot of topics that could be added to the book but there is hardly anything that could have been left out! However, a list of books for further reading should have been added.

This book will be most valuable for students at the second year M.Sc. level or the first year of a Ph.D. programme.

After completing a course from Sarason's book, a student will be able to study any one of the following books. These discuss related material at an advanced level.

Suggested Further Reading

L V Ahlfors. Conformal Invariants; Topics in Geometric Function Theory. McGraw Hill. 1973.

This book is recommended for a student interested in Riemann surfaces.

SD Fisher. Function Theory on Planar Domains; A Second Course in Complex Analysis. John Wiley & Sons. 1983.

This book is for any one interested in operator theory, H^p spaces etc.

R Narasimhan. Complex Analysis in One Variable. Birkhauser. 1985.

This book serves as good preliminary reading for someone interested in complex analysis in several variables.

Gadadhar Misra is with Indian Statistical Institute, 8th Mile, Mysore Road, Bangalore 560 059, India.



Another Uncertainty Principle ... As far as the laws of mathematics refer to reality, they are not certain, and as far as they are certain, they do not refer to reality. - *Albert Einstein.*

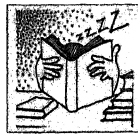


Otto Warburg's reply ... A journalist once asked Otto Warburg: 'People say that you are a great scientist but a rotten human being. What is your reaction?' Warburg's reply: 'I am glad that they do not say the other way around.'



Deceit in History ... John Dalton, the great nineteenth-century chemist who discovered the laws of chemical combination and proved the existence of different types of atoms, published elegant results that no present-day chemist has been able to repeat (from *Betrayers of the Truth* by W Broad and N Wade).

Books Received



Mapping our Genes

Lois Wingerson
Plume, USA
1990, US \$10.50.

Origins

Richard E Leakey and Roger Lewin
Penguin Books, USA
1991, Rs.362.

The Medusa and the Snail

Lewis Thomas
Penguin Books, USA
1995, Rs.333.

The Vanishing Mystery

Ecological Mystery
Kathryn Phillips
Penguin Books
1994, Rs.455.

Analysis of Thin Concrete Shells

(Second Revised Edition)
K Chandrashekhara
New Age International Ltd.
1995, Rs.650.

Journey Through Genius: The Great Theorems of Mathematics

William Dunham
Penguin Books
1990, Rs.310.

Mathematician's Apology

G H Hardy
Bridge University Press
1940, Rs.175.

Mechanics and General Properties of Matter

D P Raychaudhuri and S N Maiti
Book Syndicate Pvt. Ltd.
1993, Rs.110.

Allied and Applied Physics

(for B.Sc. Physics Students)
V S John and P Suja John
Jega Publications
1995, Rs.65.

Nuclear Physics

for College Students)
John and P Suja John
Jega Publications
1996, Rs.55.

Basic Ergodi Theory (TRIM-6)

M G Nadkarni
Hindustan Book Agency
1995.

Linear Algebra and Linear Models (TRIM)

R B Bapat
Hindustan Book Agency
1993.

Mem: A User's Manual

Mayalakshmi, K S Radha,
Vandana Shiva
CIKS, Madras
Rs.75.

Harmonic Analysis - II ed. (Texts and Reading in Mathematics - TRIM-7)

Henry Helson
Hindustan Book Agency
1995.

Linear Algebra - II ed. (TRIM-4)

Henry Helson
Hindustan Book Agency
1994.

Acknowledgements

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Errata

Vol.1 No.2 (1996) Page 32: The last three sentences in the second paragraph should read: "A device that does not plug into a PC does not live long. On the other hand, devices that do plug into PCs can be had from many vendors. They become cheaper and more powerful with time as their technology improves".

Vol.1 No.3 (1996) Page 31: At the bottom right corner of Figure 1 (pedigree analysis) the four individuals now shown as a single family belong to two separate families as per the line connecting them to their parents.

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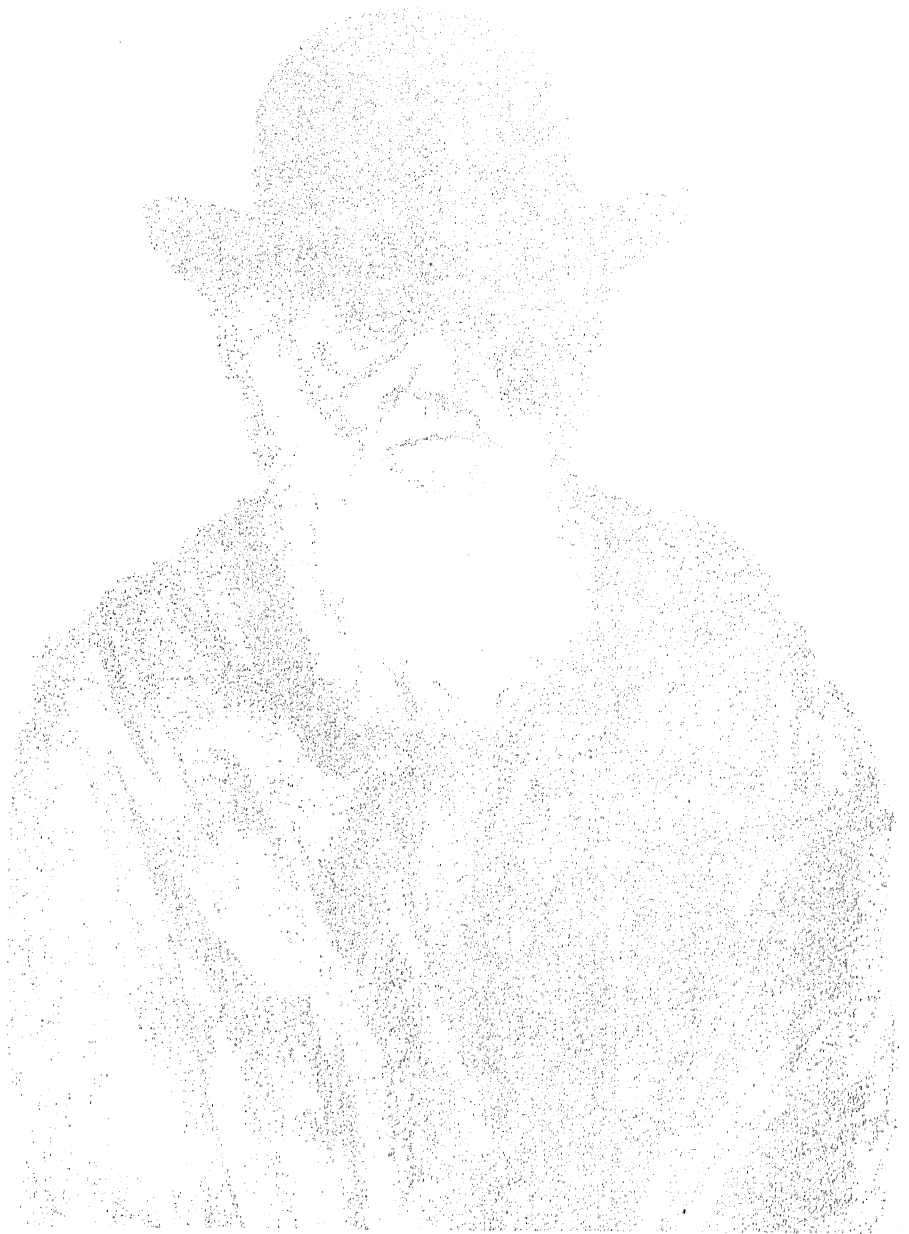


Charles Robert Darwin (1809-1882) was the son of a country doctor. He was educated to be a priest and a physician but characterizing medicine to be a "bestly profession" he gave it up to become a naturalist. Although he received no salary he became the drinking companion of the captain of the ship 'Beagle' when he was 22 years old.

Through his observations during the course of his voyages to distant shores and islands, he found the creationist explanation unsatisfactory and developed his own ideas on the mechanism of evolution. He put forward his theory of natural selection in his book 'The Origin of Species by Means of Natural Selection or The Preservation of Favoured Races in the Struggle for Life' (1859), the first edition of which was sold out on the first day. Although the actual ideas in the book had evolved in Darwin's mind way back in 1835, it was only in 1858 when he was forced to publish a paper together with A R Wallace, who had developed almost the same views independently, that his theory was broadcast to the world — a world in which almost nothing was known about inheritance, where people believed that only four major classes of animals existed and that all of it was made by God!

Darwin's theory of natural selection has so transformed our world that it tends to foreshadow his many other remarkable contributions. He has written 11 books whose topics range from fossils to domestic animals and coral reefs to fertilization in plants. In this list is a special volume 'The Descent of Man and Selection in Relation to Sex' almost as large as 'The Origin of Species'. It proposed two ideas: first it made a strong and clear case for the "monkey question" which claims that humans have descended from apes and second that the choice exercised by females during mate selection tends to produce novel forms of evolution that might even run counter to natural selection.

Darwin thought that adaptability to the environment is the key to success for every organism in the world. Applying this same rule to him, it is indeed remarkable that he has survived this long in the technocratic world of today.



Charles Robert Darwin
1809-1882